Naval Research Laboratory

Washington, DC 20375-5320

NRL/MR/6180--03-8709

The Evaluation of the Autonomic Fire Suppression System Concept of Operations and PDA Cooling Effectiveness

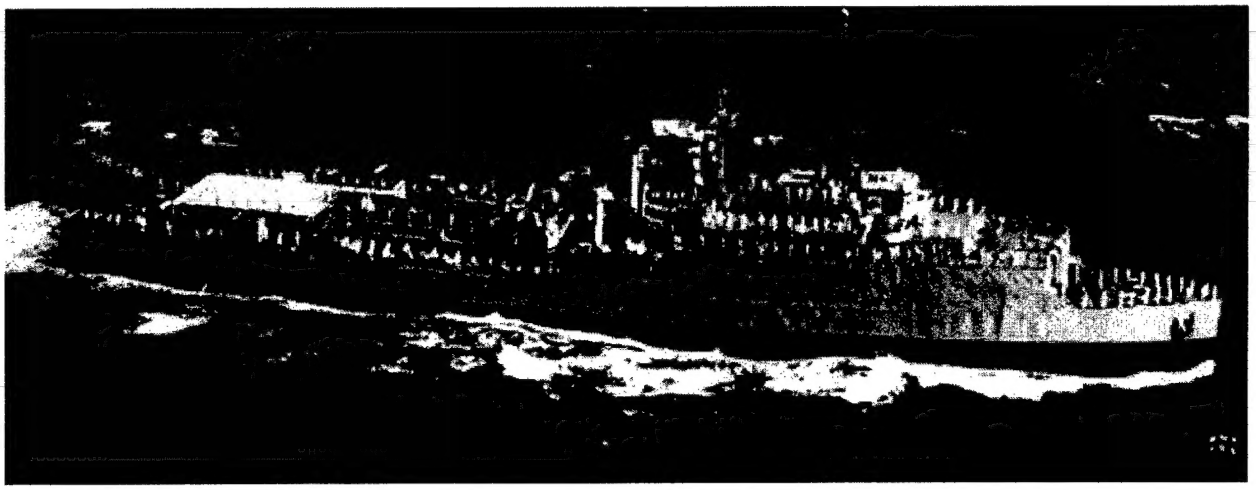
ARIAM C. LUERS
SCOTT A. HILL
JOSEPH L. SCHEFFEY
HUNG V. PHAM

Hughes Associates, Inc.
Baltimore, MD

JOHN P. FARLEY
FREDERICK W. WILLIAMS

Navy Technology Center for Safety and Survivability
Chemistry Division

September 30, 2003



REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
September 30, 2003	Memorandum Report	September 30, 2002-June 1, 2003

4. TITLE AND SUBTITLE

The Evaluation of the Autonomic Fire Suppression System Concept of Operations and PDA Cooling Effectiveness

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Ariam C. Luers,* Scott A. Hill,* Joseph L. Scheffey,* Hung V. Pham,*
John P. Farley, and Frederick W. Williams

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Research Laboratory, Code 6180
4555 Overlook Avenue, SW
Washington, DC 20375-5320

8. PERFORMING ORGANIZATION REPORT NUMBER

NRL/MR/6180--03-8709

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Naval Sea Systems Command
1333 Isaac Hull Avenue, SE
Washington Navy Yard, DC 20376

10. SPONSOR / MONITOR'S ACRONYM(S)

11. SPONSOR / MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

*Hughes Associates, Inc., 3610 Commerce Drive, Suite 817, Baltimore, MD 21227

14. ABSTRACT

This is the preliminary test report analyzing the DD(X) CONOPS for DC manning and PDA(F) cooling. These tests were conducted in May 2003 on the ex-USS *Shadwell.* A variety of peacetime and combat damage fire scenarios were evaluated as part of this test series. This report contains a brief summary of the events for each test. The following summarizes the preliminary conclusions for these tests. A properly trained damage control team, familiar with the layout of the DD(X) is essential for optimum DC response. The need for modes of operation for the DD(X), PDA(F), and APDA(F) water mist systems should be analyzed. PDA cooling using sidewall water mist nozzles has been shown to be effective in reducing temperatures and suppressing the fire. Investigators are an essential part of the DC organizations. Communications have been and still are a problem.

15. SUBJECT TERMS

Fire; Fire suppression; Water mist; Sidewall nozzle

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Frederick W. Williams
Unclassified	Unclassified	Unclassified	UL	57	19b. TELEPHONE NUMBER *(include area code)* 202-767-2476

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

CONTENTS

THE EVALUATION OF THE AUTONOMIC FIRE SUPPRESSION SYSTEM CONCEPT OF OPERATIONS AND PDA COOLING EFFECTIVENESS

1.0 INTRODUCTION

The Naval Sea Systems Command (PMS 500) and Northrop Grumman Ship Systems (NGSS) have developed a risk mitigation program to augment and support the development of the DD(X) Autonomic Fire Suppression System (AFSS). A key element of the AFSS involves the use of new concepts, equipment, and technologies to offset reductions in manning. One of the systems being considered for DD(X) is a Primary Damage Area (PDA) cooling system designed to thermally manage the PDA(F). A reduced manning organization and Concept of Operations (CONOPS) were developed for DD(X) [1] based on lessons learned during the Damage Control – Automation for Reduced Manning (DC-ARM) program. The interaction and integration of the proposed AFSS systems with the manning organization and CONOPS were evaluated during a series of tests sponsored by NGSS. The tests were conducted on the ex-USS *Shadwell*, the Navy's full-scale RDT&E facility in Mobile, Alabama [2].

2.0 OBJECTIVES

The objectives of this test series were to evaluate the current DD(X) AFSS concept of operations (CONOPS) in support of completing the EDM design and to evaluate the effectiveness of the proposed PDA cooling system. This included an evaluation of the proposed Damage Control (DC) manning organization and concept of operations under both peacetime and combat damage conditions. Specifically, the organization, number of people, doctrine, and chain of command of the Rapid Response Team (RRT), repair parties, and DC Central team were evaluated. Additionally, the transition from the RRT response to the inclusion of a repair party with further transition to a Condition I response was investigated.

In addition, interaction between personnel and damage control systems was also evaluated. These systems included:

- Water Mist Fire Suppression System,
- PDA Cooling System, and
- Ship-wide Video System.

These systems interfaced directly with the damage control supervisory control system (SCS). The supervisory control system provided the Damage Control Officer (DCO) with overall situation awareness and automatic control of the suppression systems.

Manuscript approved August 11, 2003.

3.0 TEST SETUP

3.1 General Description

The test area, which consisted primarily of FR 15 to FR 29 on the main through fifth decks (i.e., hold level), was originally configured to simulate the DDG 51 platform. This area is also representative of the proposed DD(X) configuration. Figures 1-5 provide an overview of the test area and compartment designations. Compartments that were not included in the test area have been hatched.

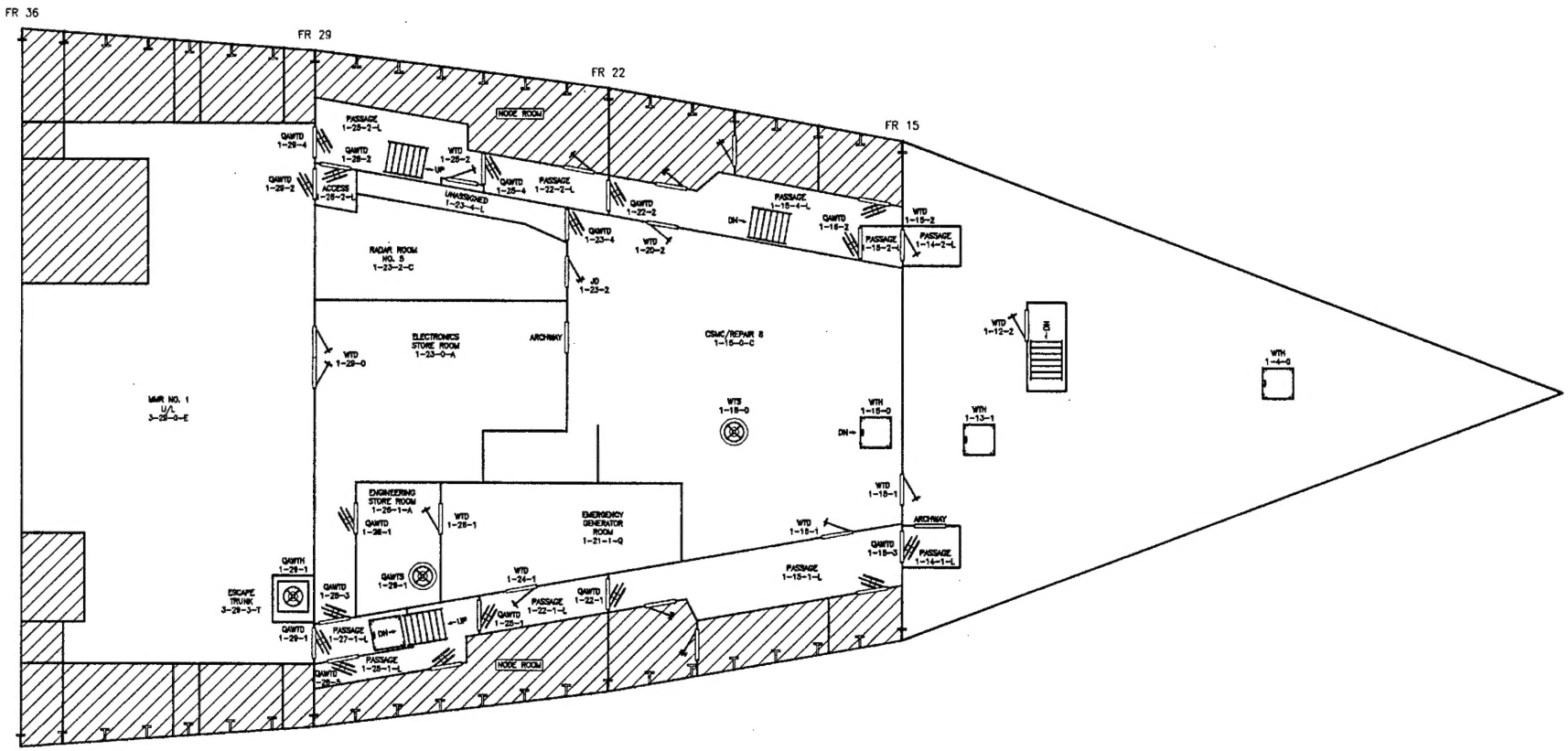
For the combat damage tests, damage to the PDA(F) was simulated. A large vent from the Comm Center to weather was opened on the starboard side. Internal damage was simulated by removing blast panels installed in the second and third decks. These openings provided free communication between the Comm Center and CIC/CPO Living and the Comm Center and AMR No. 1. The dashed line in Fig. 3 represents bulkheads destroyed by the blast.

3.2 Damage Control Organization

The proposed DD(X) DC organization was based on the results of the DC-ARM program. The aim of the DC-ARM program was to develop the technologies necessary for automated shipboard damage assessment and casualty response for timely mitigation of shipboard fire and flooding conditions and thus permit major reductions in DC manning. A series of demonstrations (FY 98, FY 00, and FY 01) were conducted in support of this test program [3-5].

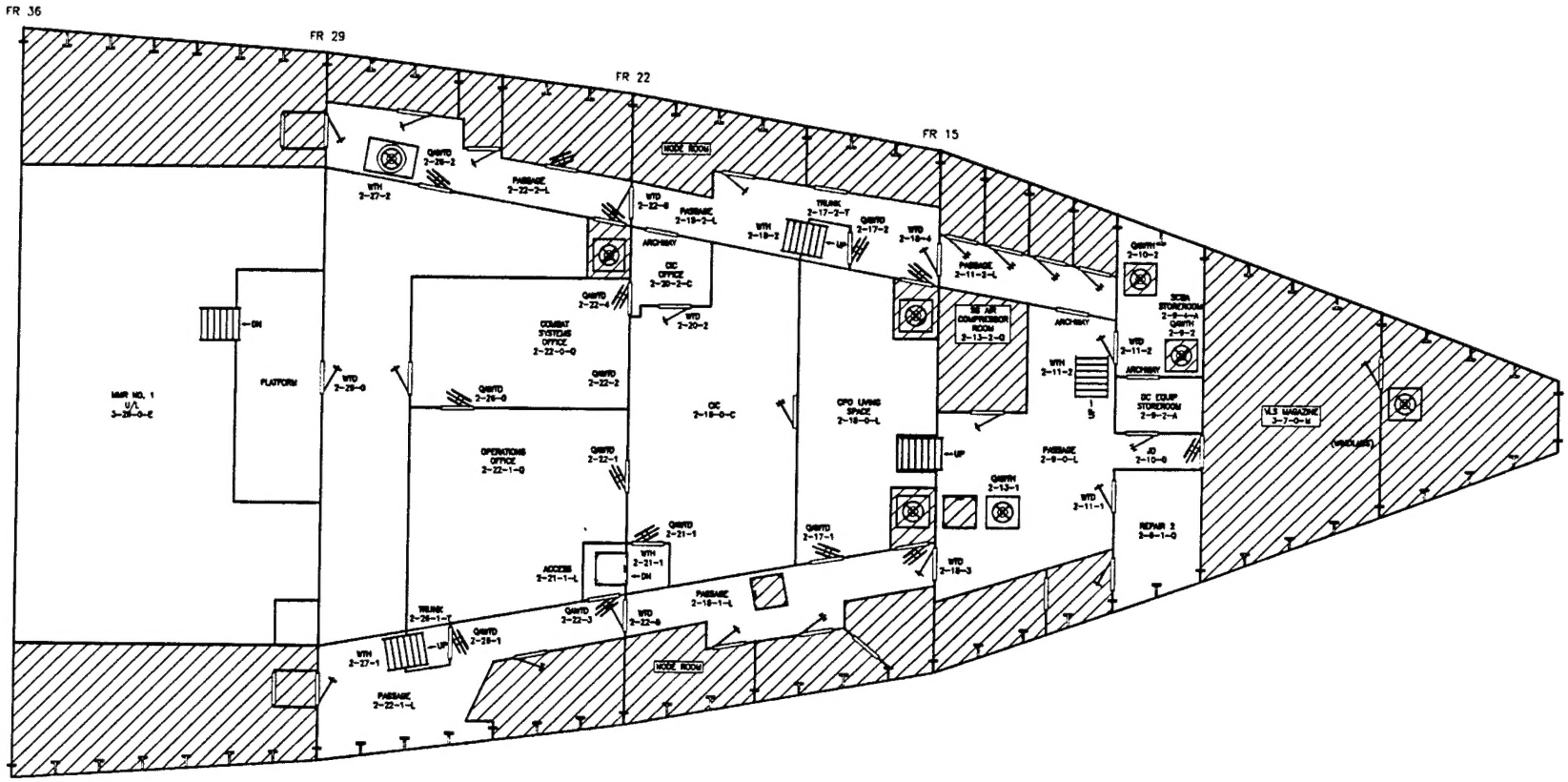
For this test series, the DC organization consisted of a total of 33 to 35 people, arranged as shown in Table 1. The Rapid Response Team (RRT) included two Primary Responders, a Scene Leader, and a three-person Attack Team. The RRT made the initial response to a peacetime fire with the goal of extinguishing fires before they could grow.

For the tests conducted during Condition I, the RRT assumed responsibility for the Casualty Coordinator and Repair Locker Communicator, while the remaining four members transitioned to one of the two Backup Attack Teams. The remaining Repair Locker Team included a four-person Backup Attack Team and a three-person Support Team. DC Central consisted of the Damage Control Officer (DCO), the DC Watch stander/Console Operator, the DC Communicator/Plotter and the Automation Repair Team (ART)/Battle Damage Assessment Team (BDAT). The ART/BDAT consisted of as many as three (3) two-person investigation teams assigned to the DCO.



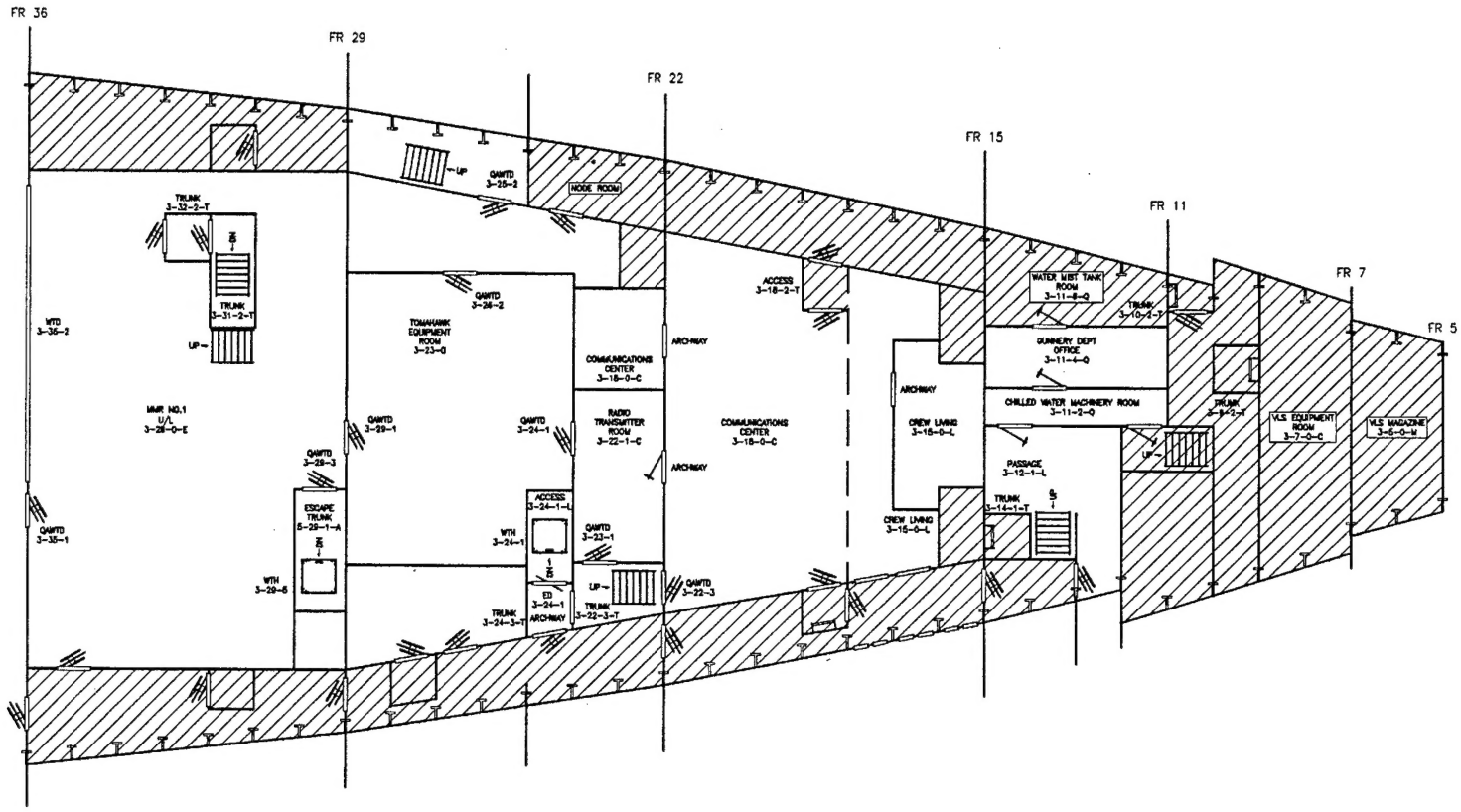
NOTE:
HATCHED AREAS ▨ ARE NOT PART OF TEST AREA.

Fig. 1 – Layout of the main deck



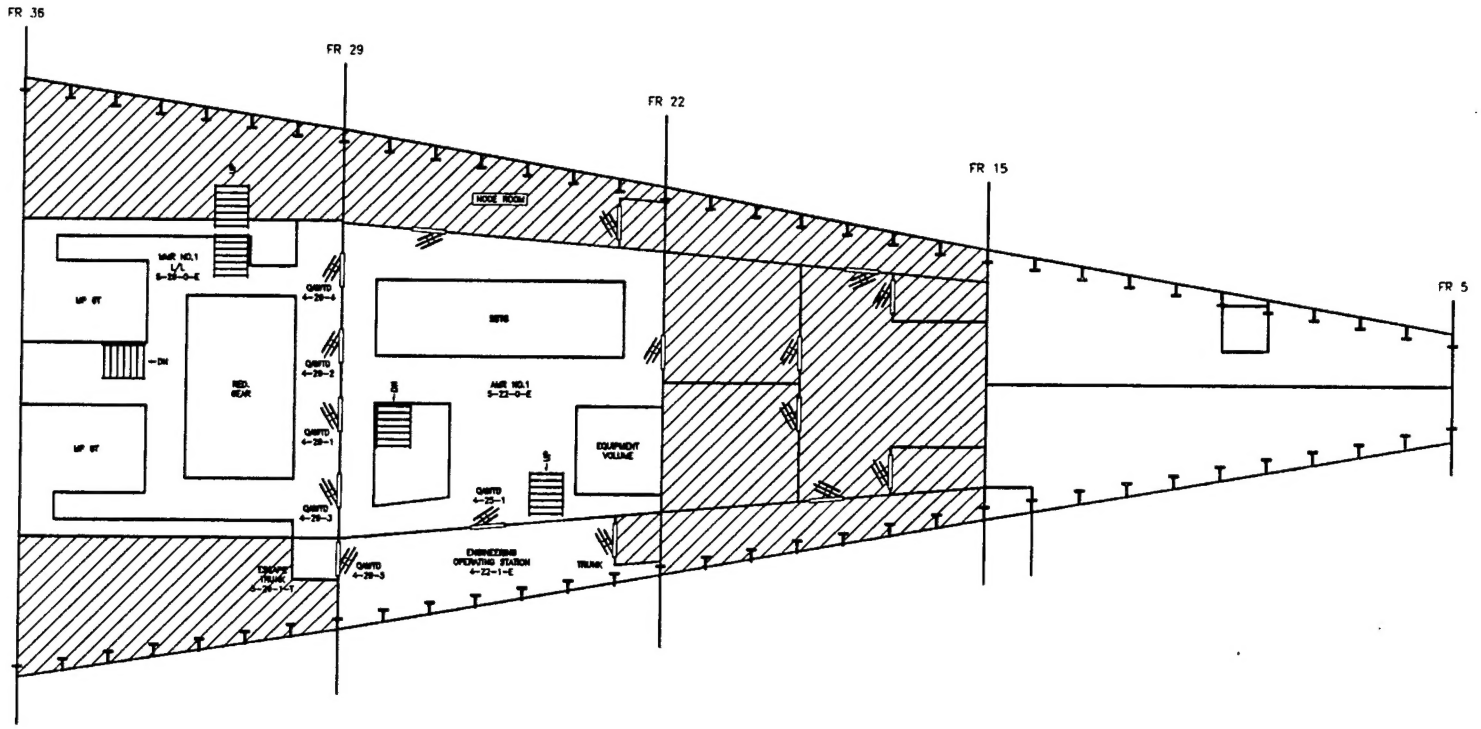
NOTE:
HATCHED AREAS ▨ ARE NOT PART OF TEST AREA.

Fig. 2 – Layout of the second deck



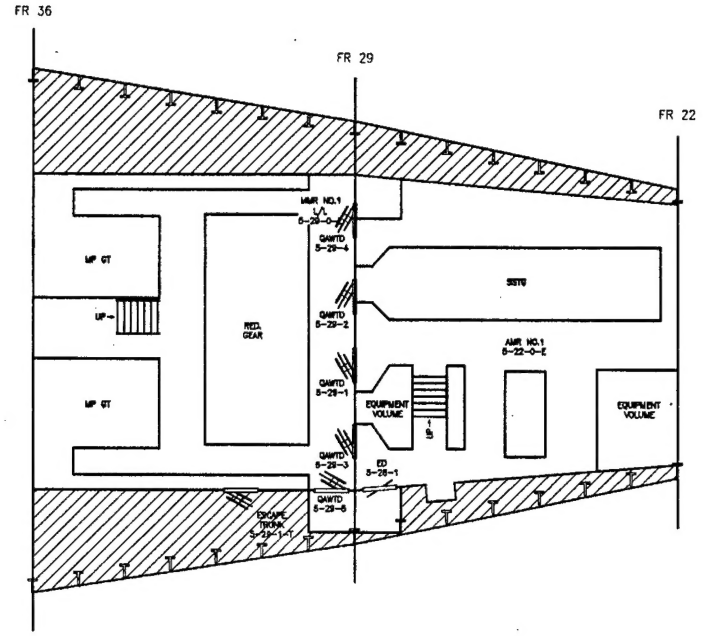
NOTE:
HATCHED AREAS ▨ ARE NOT PART OF TEST AREA.

Fig. 3 – Layout of the third deck



NOTE:
HATCHED AREAS ▨ ARE NOT PART OF TEST AREA.

Fig. 4 – Layout of the fourth deck



NOTE:
HATCHED AREAS ▨ ARE NOT PART OF TEST AREA.

Fig. 5 – Layout of the hold level

Table 1. Summary of DC Organization

Location	Responsibility	Number of Personnel	Comment
DC Central	DCO	1	
	DC Watch stander/Console Operator	1	
	DC Communicator/Plotter	1	
	ART/BDAT	4-6	During Condition III members of BDAT will man the DC supervision watch in DCC
Repair 2	RRT	6	
	Backup Attack Team	4	One (4) person team
	Support Team	3	
Repair 3	RRT	6	
	Backup Attack Team	4	One (4) person team
	Support Team	3	

Wire Fire Communications (WIFCOM), sound powered phones (2JZ) and the ships' general announcing system (1MC) were used for damage control communications. Communication links were separated by DC function and were organized as follows:

- The DC Watch stander/Console Operator communicated directly with the Repair Locker Communicator using the sound powered phone circuit. This link enabled the DC Watch stander to convey the directed commands from the DCO to the Casualty Coordinator at the Repair Locker.
- The DCO, DC Communicator/Plotter and ART/BDAT used WIFCOM. The investigation teams would receive orders from the DCO and the DC Communicator/Plotter and DCO would receive reports from these teams.
- The Casualty Coordinator and Repair Locker Team Leaders used a separate WIFCOM channel. This allowed the Casualty Coordinator to manage and direct the actions of the Attack and Support Teams.

3.3 Firefighting Equipment

The locations for fire main related firefighting equipment and portable extinguishers are shown in Figs. 6 through 10. Fire main related firefighting equipment included fire plugs, two 1.9 cm (0.75 in.) fresh water hose reels and two 3.8 cm (1.5 in.) simulated AFFF hose reels. The AFFF hose reels were actually supplied with fresh water and were installed to simulate the AFFF hose reels provided on the DDG. Fire plugs (3.8 cm (1.5 in.)) sea water) were installed such that every part of the test area could be serviced by two fire plugs using no more than 30 m (100 ft) of fire hose from each plug (Figs. 6 and 7). The fire plugs were located near vertical accesses so that progressive firefighting starting from the DC deck was less difficult. One 1.9 cm (0.75 in.) fresh water hose reel was located near the port side entrance into CIC. The other fresh water hose reel was located near the starboard side entrance into CIC, simulating the existing firefighting equipment available to combat a fire in CIC. These locations are shown in Fig. 7.

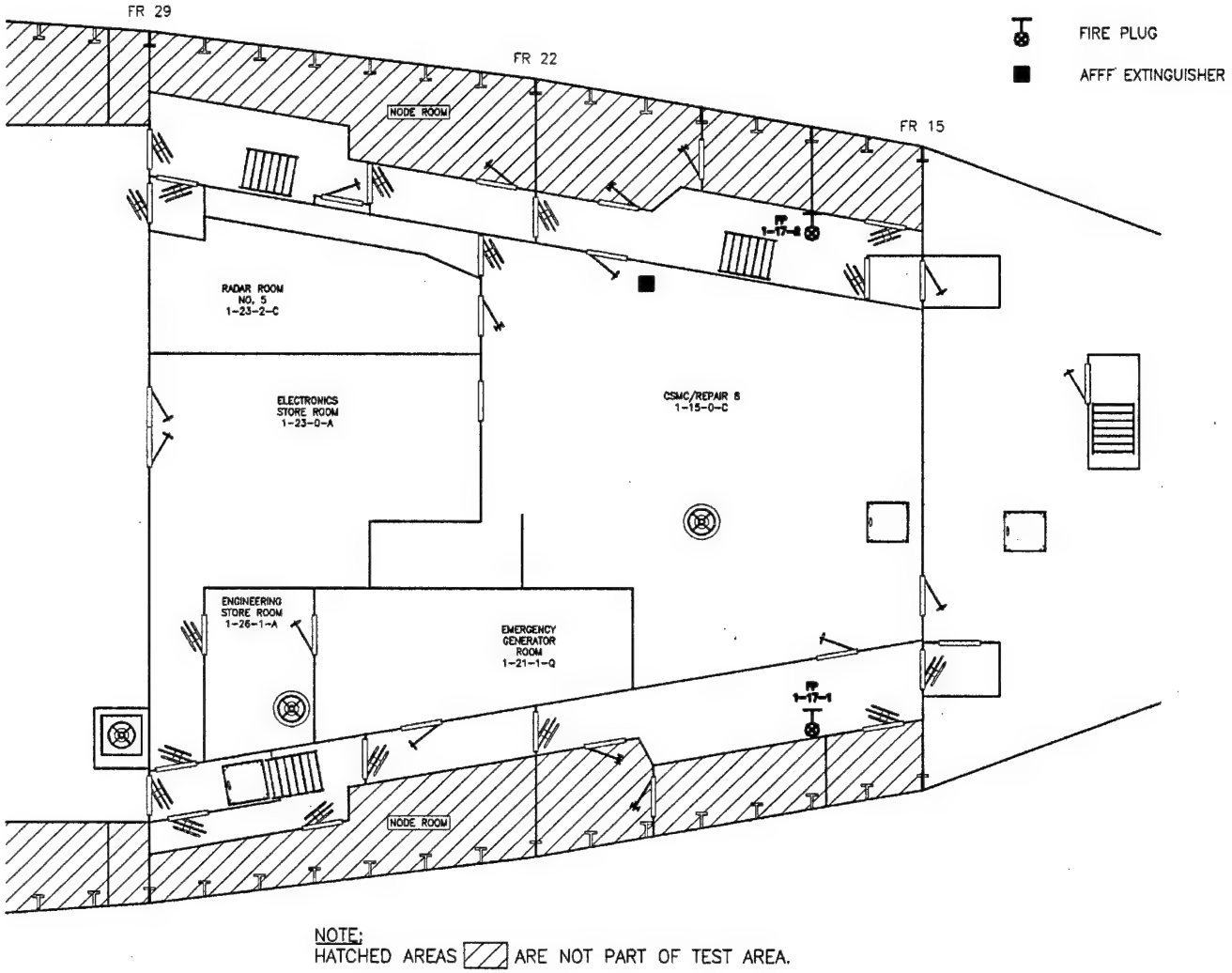


Fig. 6 – Location of firefighting equipment on the main deck

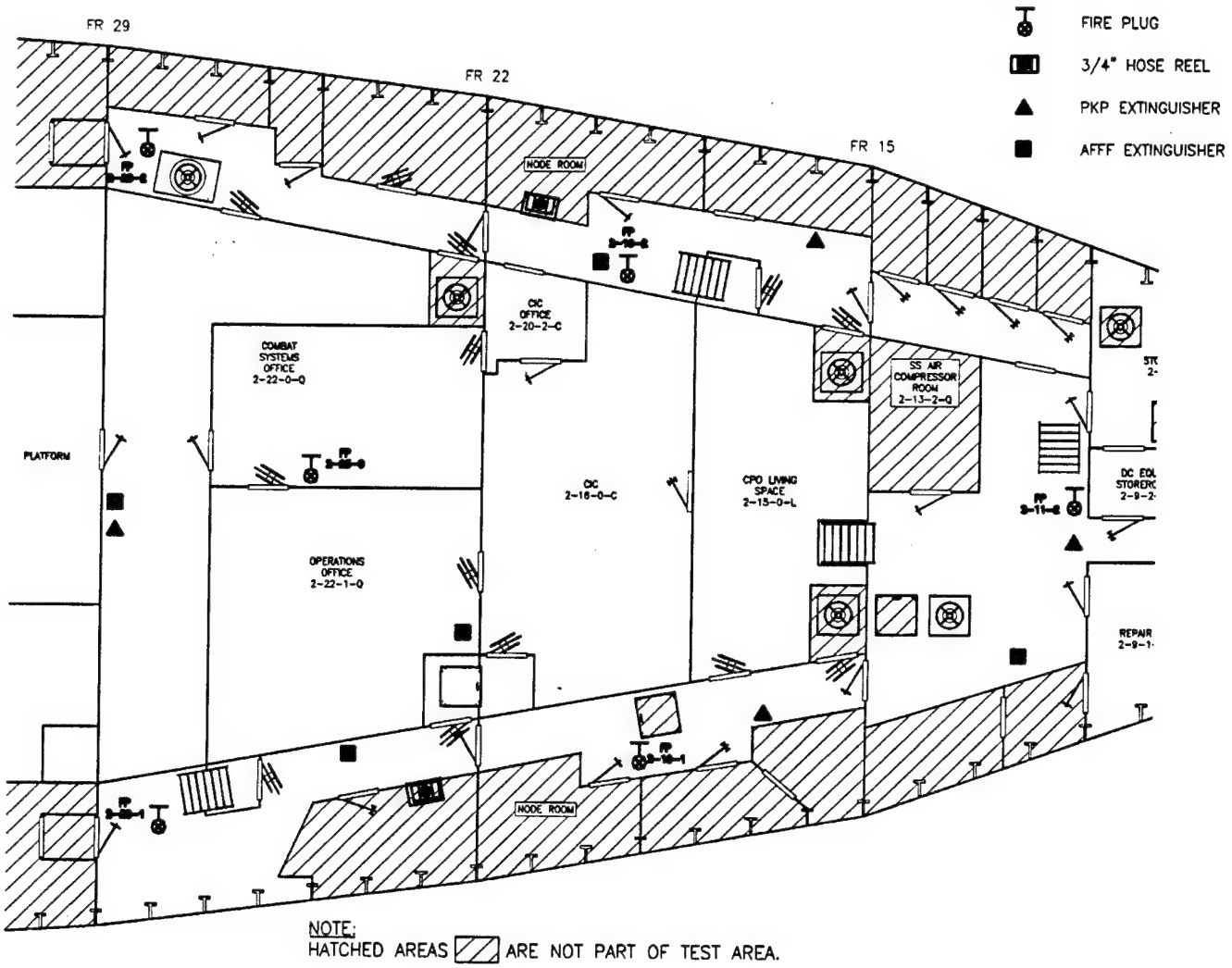


Fig. 7 – Location of firefighting equipment on the second deck

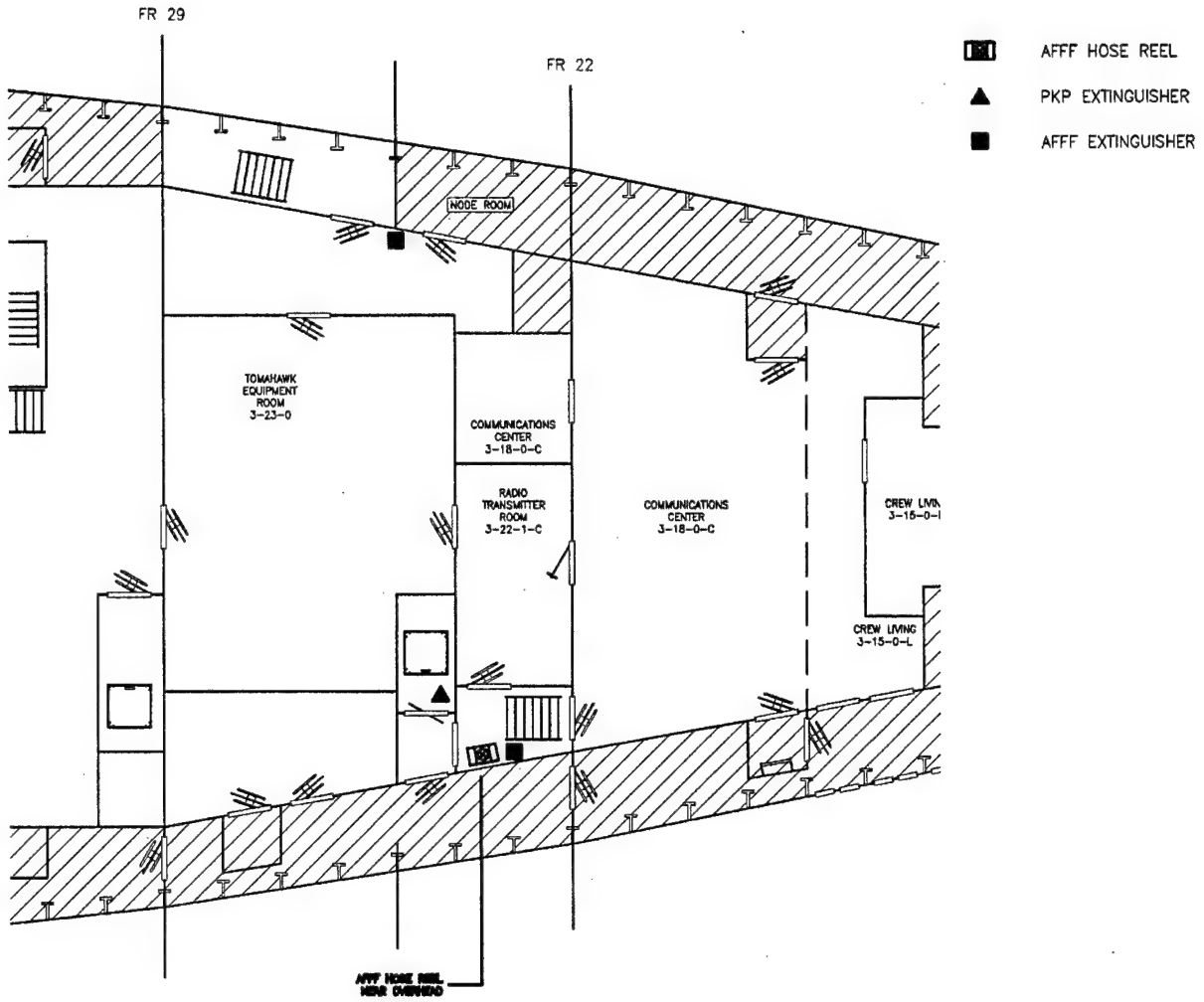


Fig. 8 – Location of firefighting equipment on the third deck

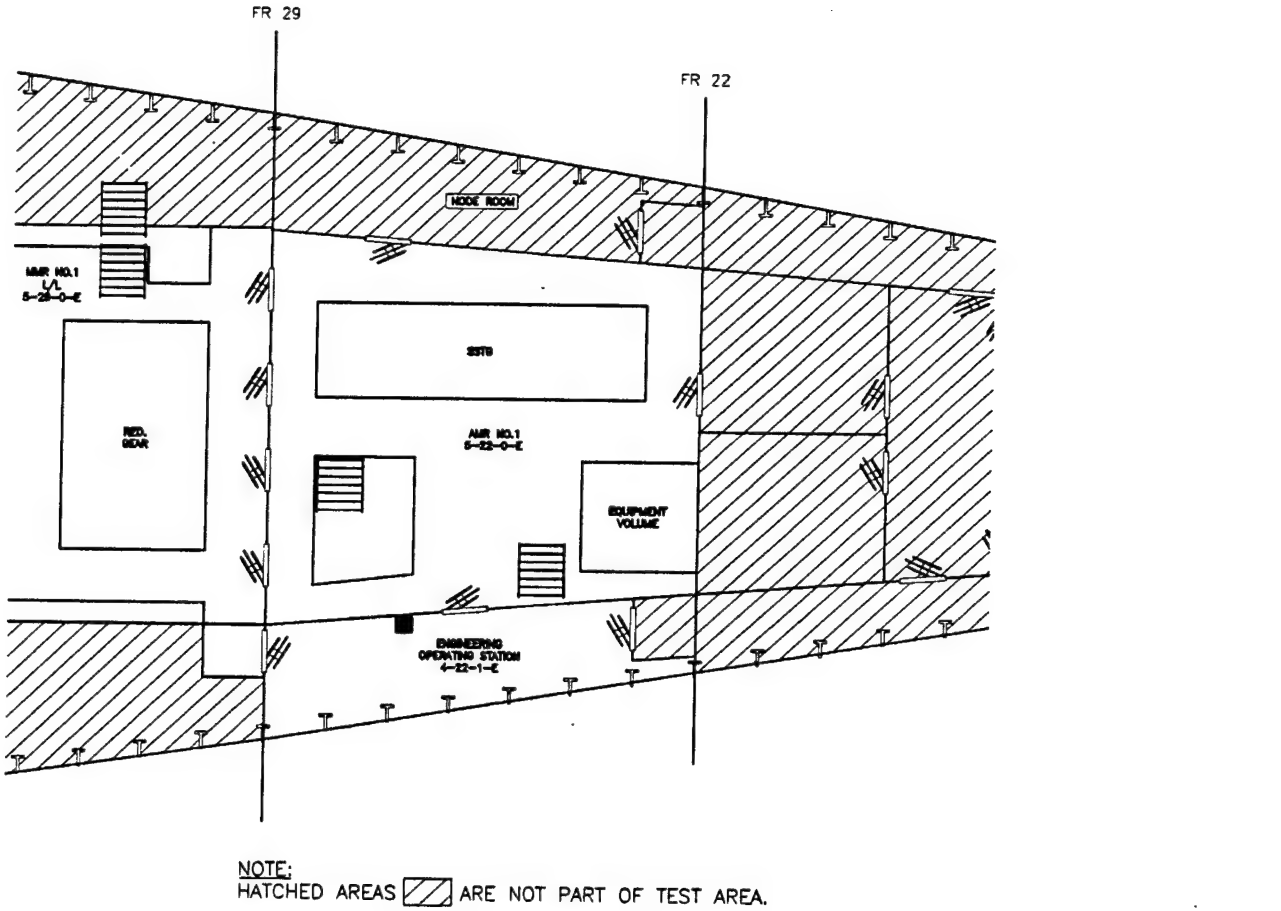
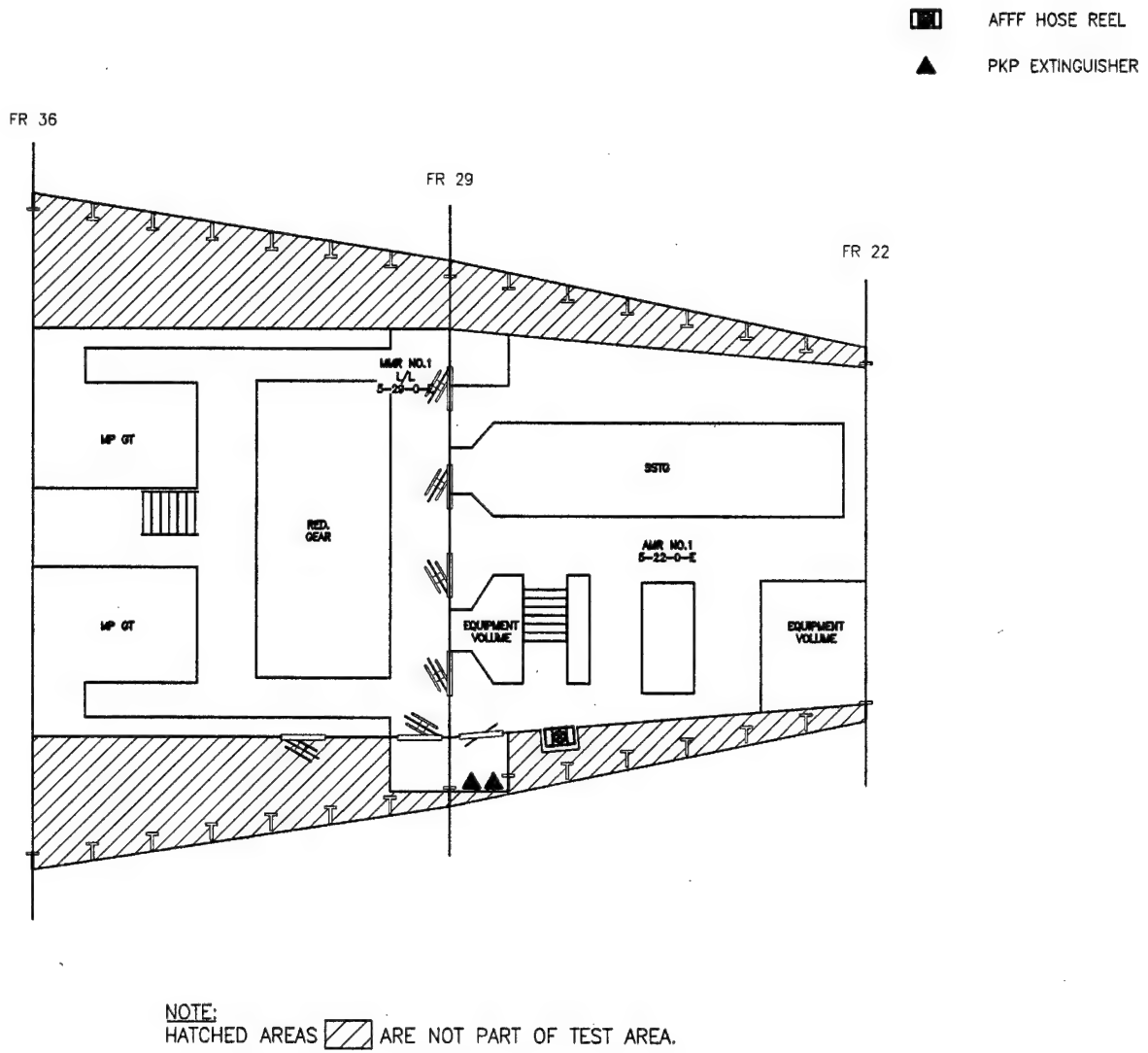


Fig. 9 – Location of firefighting equipment on the fourth deck



NOTE:
HATCHED AREAS ▨ ARE NOT PART OF TEST AREA.

Fig. 10 – Location of firefighting equipment on the hold level

A 3.8 cm (1.5 in.) AFFF hose reel was positioned outside the starboard side entrance to the Comm Center on the third deck for use in firefighting activities in AMR No. 1. A second 3.8 cm (1.5 in.) AFFF hose reel was located outside the hold level entrance to the escape trunk, between FR 27 and FR 28, for use in firefighting activities in AMR No. 1. The locations of the two AFFF hose reels are shown in Figs. 8 and 10.

In addition, essential firefighting gear, including portable extinguishers and SCBAs was distributed throughout the test area. Portable fire extinguishers, consisting of AFFF and PKP extinguishers were positioned in the test area. Personal protective equipment such as firefighting ensembles (FFEs), helmets, firefighting boots, gloves and anti-flash hoods were pre-positioned outside the repair lockers [6-8].

3.4 Ventilation

The ship ventilation system operated in two modes: normal and smoke control. Air for combustion was enhanced independently through the use of the direct current fans (E 1-15-1 and E 1-15-2). These fans were operated by the Test Team. The DCO was able to control the ship ventilation systems within the test area without affecting fire development, by using the Collective Protection System and the Smoke Ejection System.

3.4.1 Normal Mode

The Collective Protection System (CPS) onboard the ex – USS *Shadwell* was used for "normal" ventilation during these tests. The CPS ventilation system was designed to provide an overpressure of 0.5 kPa (2.0 in. of water) for a given pressure zone. The purpose of this overpressure was to provide protection from chemical, biological and radiological (CBR) hazards. CPS supply and exhaust terminals were distributed throughout the test area on the ex-USS *Shadwell* [9-10]. Three supply fans (Total Protection Supply System (TPSS) 1-31-1, 1-31-2, and 1-25-2) and three exhaust fans (Total Protection Exhaust System (TPES) 1-16-1, 1-16-2, and 1-16-4) were used to provide ventilation. Each fan had two settings, on and off. CPS ventilation remained on during each test, unless the DCO activated the Smoke Ejection System.

3.4.2 Smoke Control Mode

The design for the LPD-17 Smoke Ejection System (SES) was used to simulate the desmoking capability of the DD(X) ventilation system design. This system was mocked up and initially evaluated on the ex-USS *Shadwell* in 1998 [11-13]. The purpose of this system is to remove smoke from DC deck (second deck) passageways and to prevent smoke from entering Combat System Maintenance Central (CSMC)/Repair 8. SES terminals located in the second deck passageways provided a high air change rate within the passageways to purge smoke. SES terminals located in the main deck passageways were balanced such that the passageways were at a pressure slightly less than that in CSMC/Repair 8, thus preventing smoke infiltration into that compartment.

3.5 Fire Protection Systems

The LPD-17 high-pressure (70 bar (1000 psi)) water mist pump was used for this test series. This system was installed as part of the developmental work for LPD 17 [14-16]. The LPD-17 pump was rated for 833 Lpm at 70 bar (220 gpm at 1000 psi). The pump was located in the starboard engine room between Frames 64 and 74 on the fourth deck.

Portions of the existing water mist system installed in the forward test area were modified to supply the nozzles in the PDA(F) and APDA(F) compartments. Based on the initial results of the January-March 2003 PDA cooling tests conducted at CBD [17], Tyco AM-18 sidewall nozzles were installed in the potential PDA(F) spaces. Tyco AM-11 overhead nozzles were installed in the APDA(F) spaces. Tests were conducted with both thermally activated and open nozzles. Additional nozzle data are provided in Table 2.

The water mist system installed for the protection of the AMR No. 1, consisted of a single zone with nozzles in the overhead of the fourth deck and hold level. This system had two operating modes; on and off. No automation was used for this system. The system was controlled from a console in the ex-USS *Shadwell* Control Room if requested by the DCO. The water mist nozzles consisted of Tyco AM-4 nozzles. As the nozzles were open (deluge) type, there was no water in the piping in AMR No. 1 until the pump was activated. Additional nozzle data are provided in Table 2.

Table 2. Nozzle Information

Nozzle Model	K-factor (Lpm/bar$^{1/2}$ (gpm/psi$^{1/2}$))	Flow (Lpm (gpm))	System Pressure (bar (psi))	Activation Temperature (°C(°F))	Test Configuration
Tyco AM-18	9.0 (0.62)	32 (8.5)	12.7 (185.0)	79 (174)	PDA(F) Sidewall Nozzle
Tyco AM-11	4.7 (0.33)	16.7 (4.5)	12.7 (185.0)	79 (174)	APDA(F) Overhead Nozzle
Tyco AM-4	3.5 (0.24)	12.5 (3.3)	12.7 (185.0)	N/A	Machinery Space Nozzle

3.6 *Shadwell* Sensors

Instrumentation was installed in the various test compartments to measure temperature, smoke density (visibility), and gas concentrations. Pressure transducers and flow meters were used to measure water mist system pressure, fire main pressure and fireplug water flow rates. These data were collected on the MassComp, the *Shadwell* data acquisition computer, and were available real-time over the *Shadwell* network. The supervisory control system was able to use selected data to provide situation awareness for the DCO. In addition, these data were used to measure the performance of the reduced manning DC organization as a function of tenability conditions, response times and actions taken by the test participants. Additional data on the types and locations of instrumentation used during these tests was included in the test plan [18].

3.7 Supervisory Control System

The supervisory control system (SCS) used during these tests was similar to the system developed for the FY 01 DC-ARM demonstration by MPR Associates, Inc. The SCS is a hierarchical system that uses top level performance objectives to develop requirements for personnel [19,20]. The SCS provided overall situation awareness to the DCO and automatically controlled the suppression systems. The DCO was able to override these operations if deemed necessary. The system also integrated data from video and ex-USS *Shadwell* sensors.

The SCS operated the water mist system in two different modes of operation: Fire Suppression (FS) mode and Boundary Cooling (BC) mode. These modes of operation were the same as those used in the FY 01 DC-ARM test series. In FS mode, the SCS energized all of the water mist branches in a space. Water mist remained on until a request was made by on-scene personnel for it to be secured or the temperature in the compartment decreased below a set value. The SCS activated water mist in BC mode in compartments adjacent to those where fires had been detected or in compartments where sensor data was no longer available (independent of the compartment temperature). When the water mist system was in BC Mode, water mist was energized for approximately 30% of the BC cycle. Additional information regarding the modes of water mist operation can be found in the FY 01 DC-ARM report [5].

4.0 MEASURES OF PERFORMANCE

The measures of performance for this test series account for the various actions that must be taken to mitigate the casualty and restore the ship to normal operating condition. For peacetime fires, the goals were to prevent fires from growing to a size that could not be handled by the small group of initial responders (2 to 6 people) and to prevent fire spread from the initial ignition location. Specific performance criteria for peacetime fires included:

1. Preventing fires from exceeding 250 kW. A fire of this size can be controlled with either a portable extinguisher or small diameter hose line.

2. All fires should be totally extinguished within 15 minutes. This does not include the complete overhaul of deep-seated Class A fires.

3. Maintaining temperature of the unexposed (non-fire) side of bulkhead and deck surfaces below 200°C (392°F) at all locations to prevent ignition of combustibles in adjacent compartments due to conduction or radiation.

4. The average air temperature within the fire compartment should be less than 80°C (176°F) at all times to facilitate the casualty response.

5. Visibility should exceed 12.2 m (40.0 ft) in all compartments.

During some of the peacetime scenarios, system failures were imposed to allow the fires to grow. This was done so the response team would be required to transition from the RRT to the inclusion of the backup hose team with further transition to a full repair party response. In

these tests, the measures of performance included the ability of the organization to effect a smooth transition without a loss of continuity or situation awareness, as well as the ability to contain damage and control the fire.

For the combat damage scenarios, the goal was to contain damage to the PDA(F). This was accomplished by; 1) identifying the PDA(F) and APDA(F), 2) assessing the availability and operability of protection systems, 3) prioritizing the areas that require the fire protection assets, 4) allocating the assets to contain damage to the PDA(F), and 5) continuing these actions on a real time basis. Specific performance criteria for the combat damage scenarios included:

1. Maintaining the average upper layer air temperature in the PDA(F) to less than 250°C (482°F) to prevent fire spread to APDA(F) spaces.

2. Maintaining the temperature of the unexposed (non-fire) bulkhead and deck surfaces to less than 200°C (392°F) at all locations to prevent localized heating from causing ignition of combustibles due to conduction or radiation.

3. Maintaining an average air temperature of less than 80°C (176°F) and a visibility distance of at least 6.1 m (20.0 ft) in all APDA(F) spaces. Maintaining tenability will assist the response team as they investigate APDA(F) spaces and attempt to access the PDA(F).

For the combat damage tests, the measures of performance for the CONOPS and manning organization were the ability of the organization to contain damage and maintain situation awareness.

5.0 TEST PROCEDURES AND SCENARIOS

5.1 Peacetime Fire Scenarios

The peacetime tests were designed to evaluate the response to peacetime fires, with particular focus on growing fires that require a transition from the RRT response to a repair party. A matrix for these tests is provided in Table 3.

During the peacetime tests, the ship was at Condition III, underway in a potentially hostile area with no immediate threats detected and modified condition ZEBRA set. The DC Watch stander was stationed in DC Central prior to the start of each test. Initially, the fire main was set at condition YOKE with one fire pump on line and the other pump in standby. These initial conditions are consistent with current Fleet practice and similar to the conditions utilized in previous testing [3].

For the peacetime tests, the supervisory control system was not used as this system was not operational at the start of the test series, rather the DCO relied on information using the *Shadwell* sensors and video cameras available in the Control Room. In the event that the RRT was required to extinguish fires, portable extinguishers were considered sufficient, provided that the response was timely. During some tests, additional fuel was staged in adjacent compartments

Table 3. Test Matrix for Peacetime Fire Scenarios

Test Name	Fire Location	Fire Scenario	Comments
afss05	AMR No. 1	• Unobstructed 0.9 m (3.0 ft) x 2.4 m (8.0 ft) pan fire with 37.9 L (10.0 gal) of F76 and 9.5 L (2.5 gal) heptane • Obstructed 0.3 m (1.0 ft) x 0.3 m (1.0 ft) pan fire with 7.6 L (2 gal) heptane • Two - 0.6 m (2.0 ft) x 0.6 m (2.0 ft) x 0.6 m (2.0 ft) word cribs, located on fourth and fifth decks. Ignited by 3.8 L (1.0 gal) heptane	• Unmanned machinery space. Water mist activated within 1 minute of ignition.
afss07	AMR No. 1	• Unobstructed 0.9 m (3.0 ft) x 2.4 m (8.0 ft) pan fire with 37.9 L (10.0 gal) of F76 and 9.5 L (2.5 gal) heptane • Obstructed 0.3 m (1.0 ft) x 0.3 m (1.0 ft) pan fire with 7.6 L (2 gal) heptane • Two - 0.6 m (2.0 ft) x 0.6 m (2.0 ft) x 0.6 m (2.0 ft) word cribs, located on fourth and fifth decks. Ignited by 3.8 L (1.0 gal) heptane	• Unmanned machinery space. Water mist activated within 1 minute of ignition.
afss08	Radio Transmitter Room	• 0.9 m (3.0 ft) diameter pan fire with 18.9 L (5.0 gal) heptane. Four sheets of fiberboard measuring 1.2 m (4.0 ft) x 2.4 m (8.0 ft) 0.9 m (3.0 ft).	• Potential sympathetic ignition in Comm Center, Tomahawk Equipment Room and Operations Office. • Water mist system unavailable

Table 3. Test Matrix for Peacetime Fire Scenarios

Test Name	Fire Location	Fire Scenario	Comments
afss09	Radio Transmitter Room	• 0.9 m (3.0 ft) diameter pan fire with 18.9 L (5.0 gal) heptane. Four sheets of fiberboard and plywood measuring 1.2 m (4.0 ft) x 2.4 m (8.0 ft) 0.9 m (3.0 ft).	• Potential sympathetic ignition in Comm Center, Tomahawk Equipment Room, Operations Office and Combat Systems Office. • Water mist system unavailable
afss10	CPO Living	• 0.6 m (2.0 ft) x 0.6 m (2.0 ft) x 0.6 m (2.0 ft) word crib elevated 0.3 m (1.0 ft) above deck. Ignited by 0.3 m (1.0 ft) diameter pan containing 9.5 L (2.5 gal) heptane.	• Thermally activated water mist nozzles installed in CPO Living
afss11	CPO Living	• 0.6 m (2.0 ft) x 0.6 m (2.0 ft) x 0.6 m (2.0 ft) word crib elevated 0.3 m (1.0 ft) above deck. Ignited by 0.3 m (1.0 ft) diameter pan containing 9.5 L (2.5 gal) heptane	• Open water mist nozzles installed in CPO Living. • Locker moved in front of fire to obstruct water mist from directly reaching fire.
afss13	Radio Transmitter Room	• 0.9 m (3.0 ft) diameter pan fire with 18.9 L (5.0 gal) heptane. Four sheets of fiberboard and plywood measuring 1.2 m (4.0 ft) x 2.4 m (8.0 ft) 0.9 m (3.0 ft).	• Potential sympathetic ignition in Comm Center, Tomahawk Equipment Room, Operations Office and Combat Systems Office. • Water mist system available in Comm Center, Combat Systems Office, Operations Office and Tomahawk Equipment Room

so that the fires had the potential to grow if undetected initially or not responded to quickly. In some cases the water mist system was disabled to simulate a system failure. This resulted in a fire that required the DC organization to "flex up" and incorporate a larger response.

5.2 Combat Damage Fire Scenarios

During the combat damage scenario tests, the ship was at General Quarters, underway in a hostile area. Modified condition ZEBRA was set. DC Central and the repair lockers were manned prior to the start of the test. All of the combat damage scenario tests incorporated the damage expected from the detonation of a medium-sized warhead. Damage to the ship structure and systems was simulated. Damage to ship systems included the loss of sensors, and inoperable sections of the installed suppression and PDA cooling systems.

One basic scenario was used to define the primary damage area. The wartime damage scenario was developed using data from the Battle Damage Estimator from NSWC Carderock [21], USS *Stark* incident [22] and *ex*-USS *Dale* tests [23]. Also, flame spread guidelines based on experimental data were incorporated [24-29]. Tests differed from each other by examining the involvement of different APDA(F) compartments (i.e., spreading fire to different compartments). An overview of PDA(F) and APDA(F) compartments is provided in Figs. 11-15.

Vents representing the damage created by a weapon hit were opened in the starboard bulkhead of the Comm Center and the hull of the ex-USS *Shadwell*. Since the bulkhead needed to be reattached at the end of the test series, a lip of about 7.6 cm (3.0 in.) was left on either side of each frame. Two openings in the bulkhead between Frames 16 and 18, each approximately 1.1 m (3.5 ft) wide and 1.8 m (6.0 ft) tall were opened. A 15-20 cm (6-8 in.) sill was left at the bottom of each vent. The total area of the opening was approximately 3.9 m^2 (42 ft^2)

Fig. 16 shows the frames and stiffeners in the hull of the ex-USS *Shadwell*. The frames and the stiffeners were 0.6 m (2.0 ft) apart on center. As with the vents in the Comm Center bulkhead, a lip of about 7.6 cm (3.0 in) was provided on either side of each frame and stiffener on the hull. Five openings cut between Frames 15 and 18, each measuring approximately 0.5 m (1.5 ft.) wide and 1.8 m (6 ft) tall, were opened. As with the inboard vents, a 15-20 cm (6-8) sill was left at the bottom of each of the hull vents. The total area of the openings was approximately 4.

Blast damage to the decks was simulated via the openings in the second and third decks. The vents in the second deck permitted free communication between the Comm Center and CIC. Similarly, the large vent in the third deck allowed communication between the Comm Center and AMR No. 1. For each test, a fire was staged in the Comm Center/Crew Living and Radio Transmitter Room. A separate fire was not staged in CIC since the blast panel openings allowed flames to penetrate the deck into CIC. During some tests, the Operations Office was considered part of the PDA(F). For these tests the door between the Operations Office and CIC remained open.

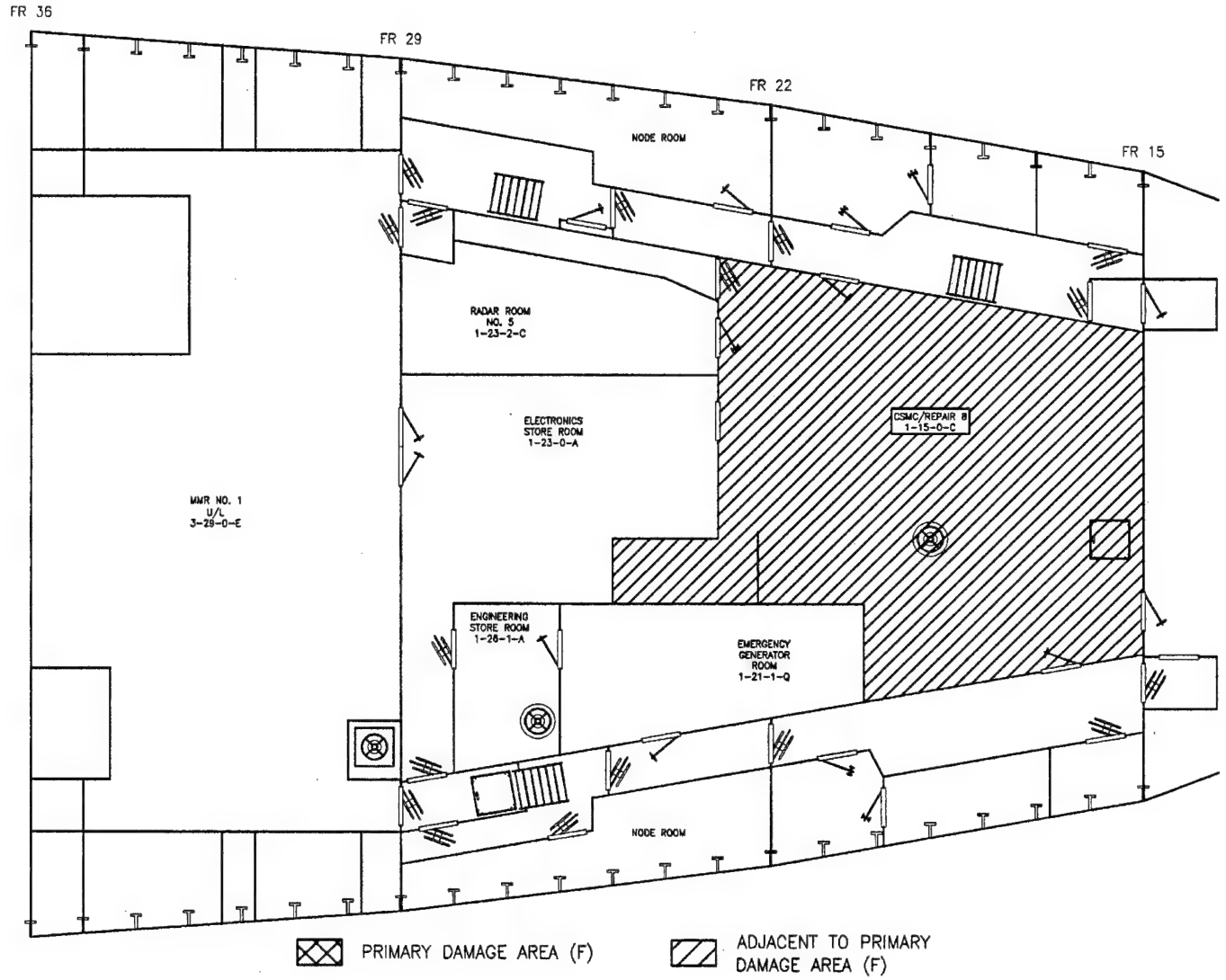


Fig. 11 – Compartment damage classification for the main deck

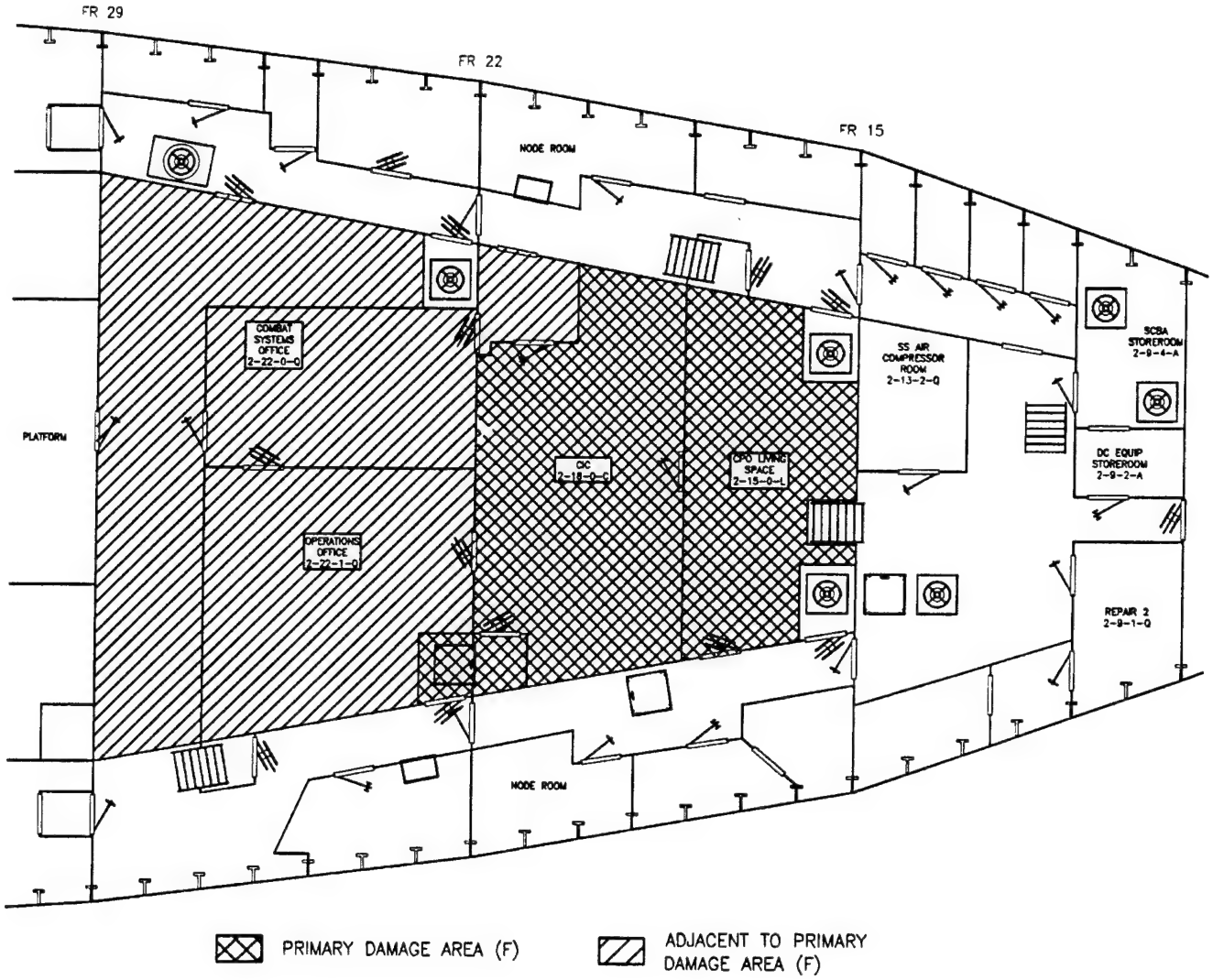


Fig. 12 – Compartment damage classification for the second deck

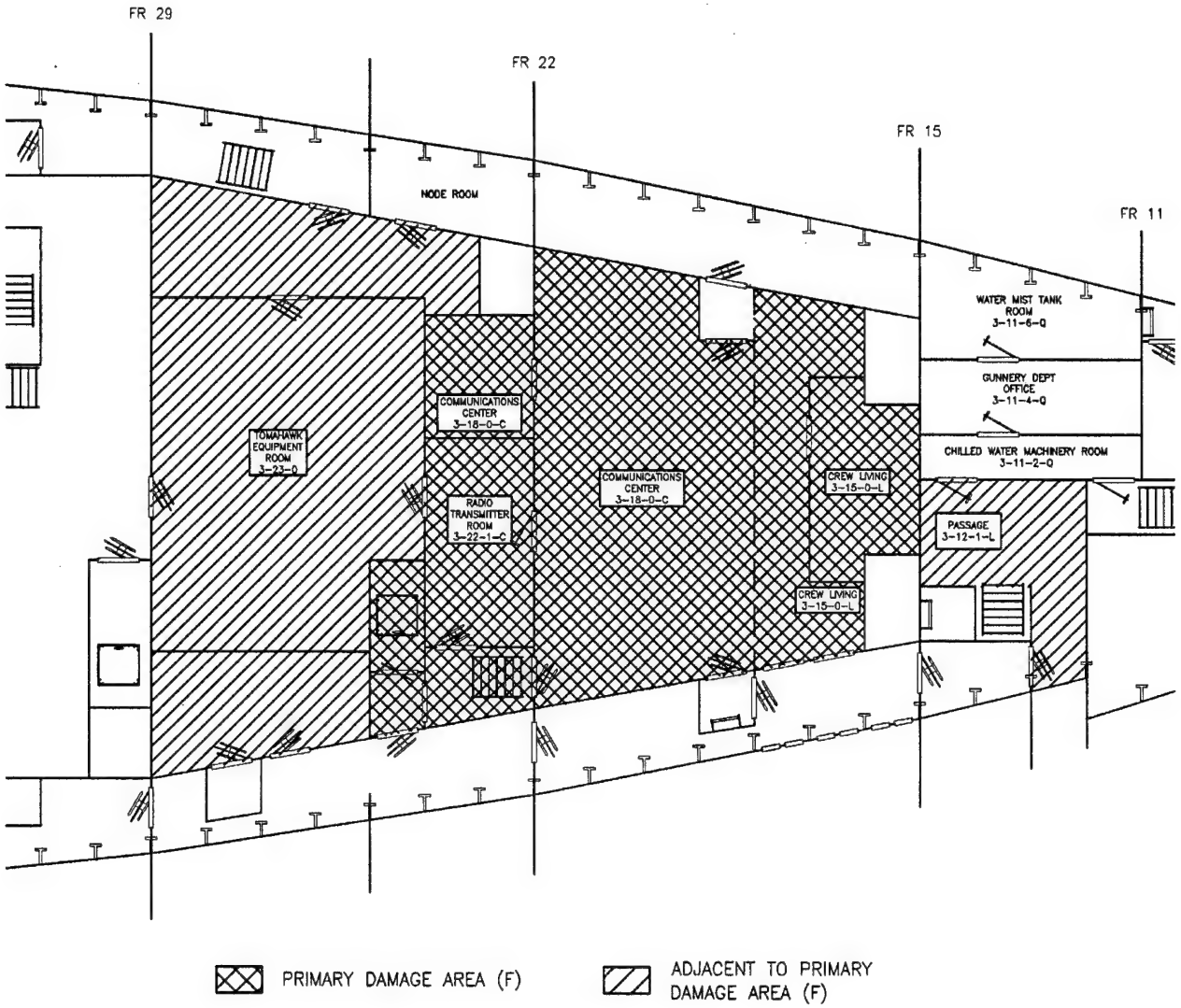


Fig. 13 – Compartment damage classification for the third deck

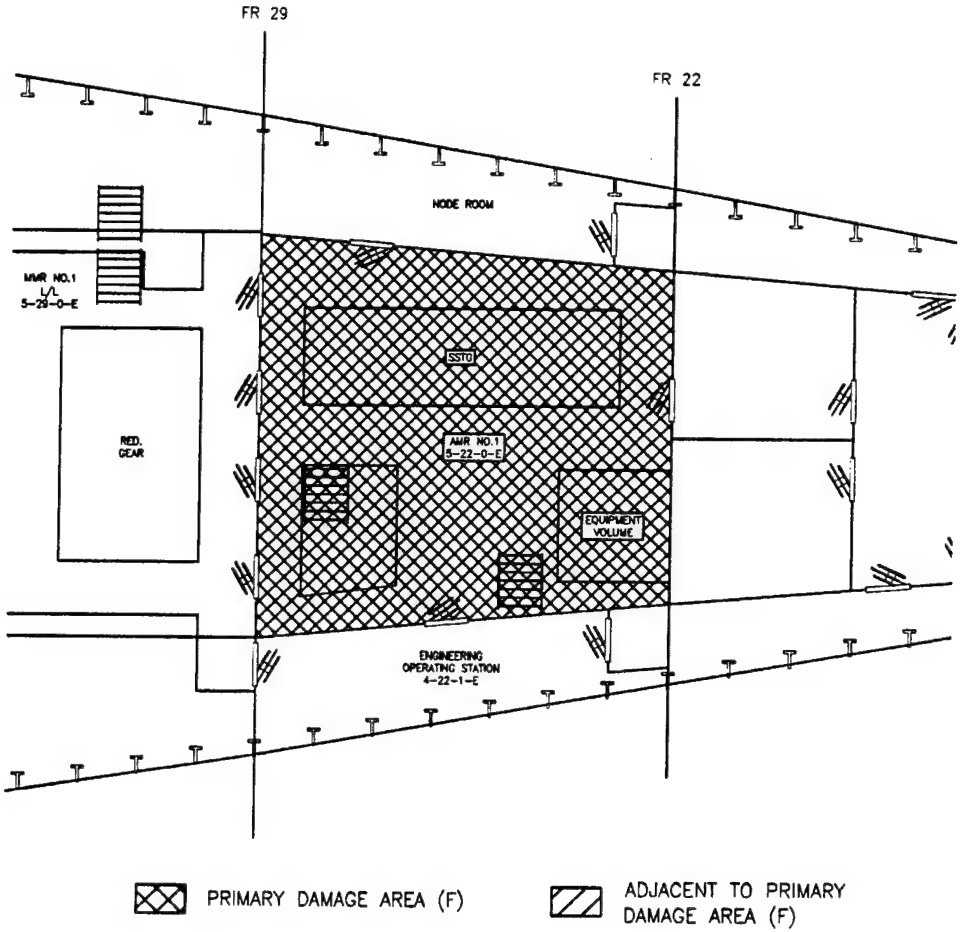


Fig. 14 – Compartment damage classification for the fourth deck

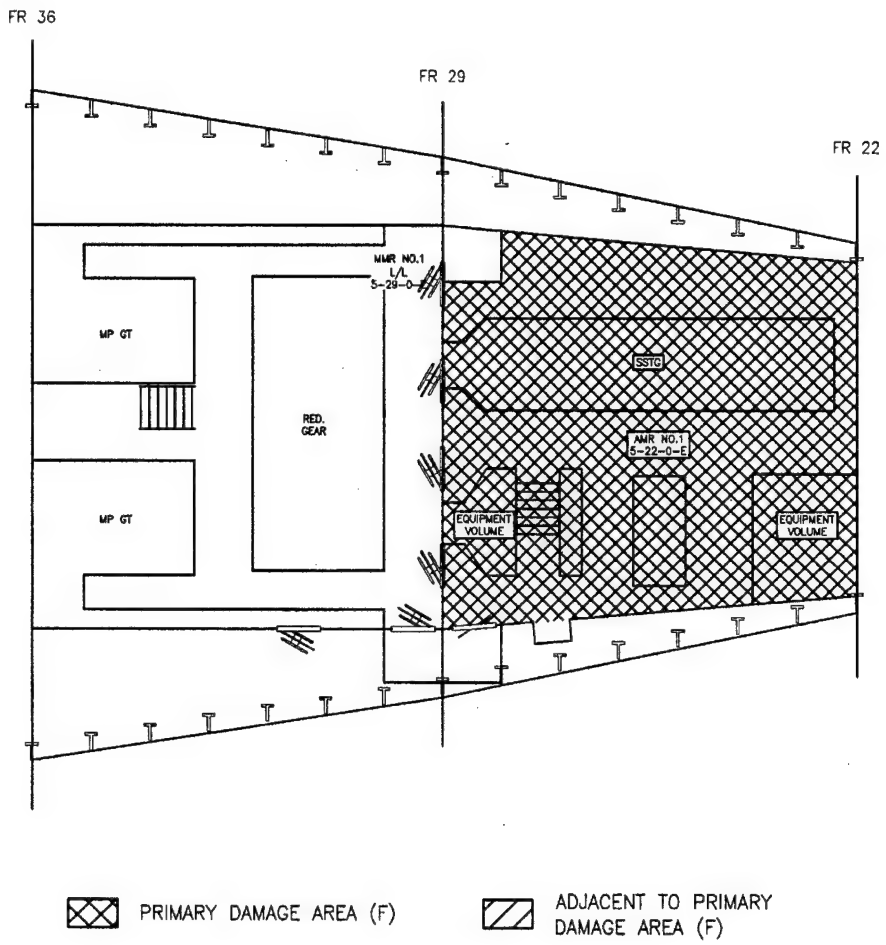


Fig. 15 – Compartment damage classification for the hold level

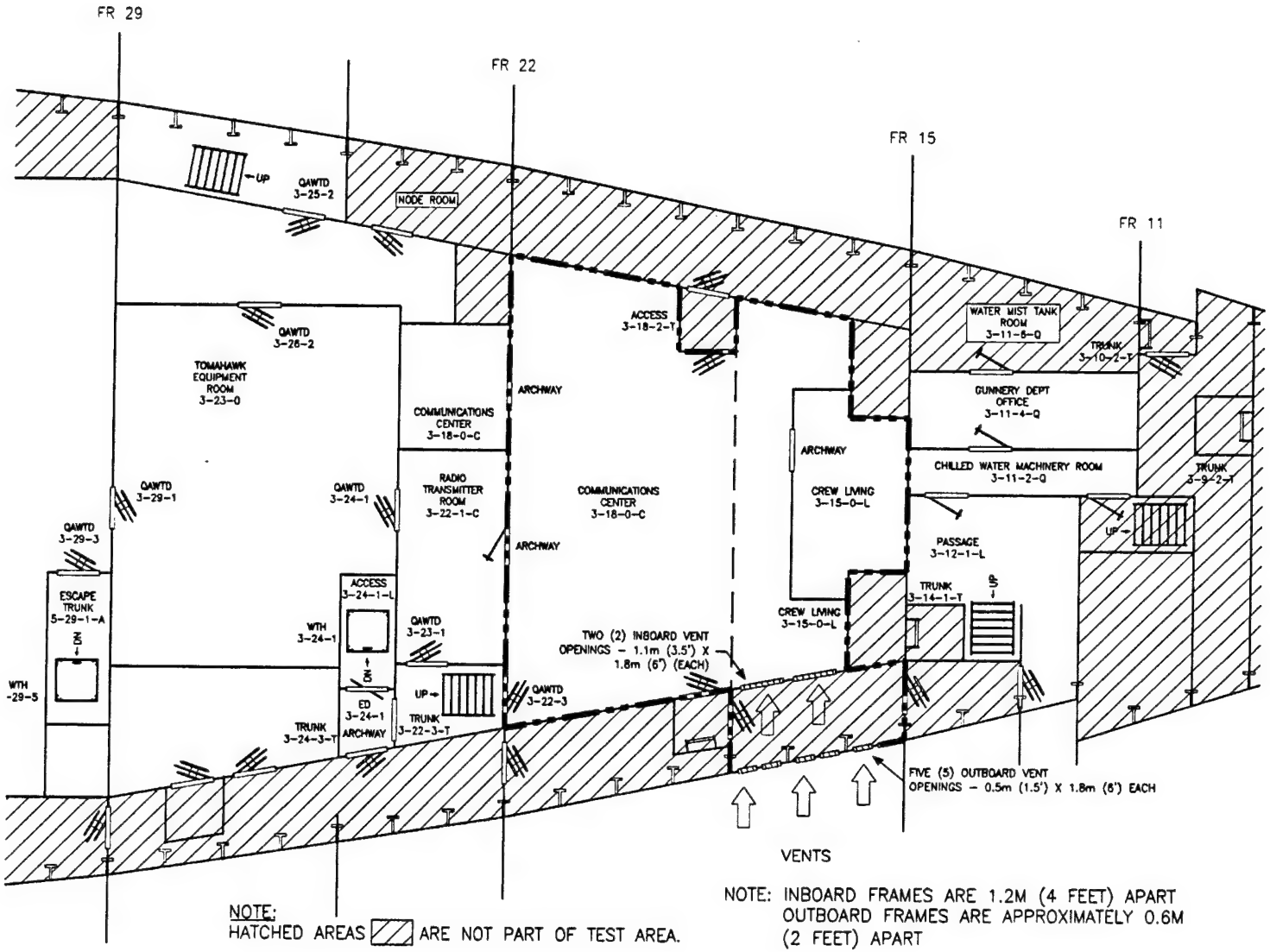


Fig. 16 - Third deck vent

Fires in the PDA(F) consisted of wood crib and heptane spray fires. The use of spray fires eliminated the need for the standard preburn required with Class A materials. The locations for these fires are shown in Figs. 17-19. Table 4 provides the fuel specifications for each fire location.

Table 4. Fire Descriptions

Location Number	Location	Primary Damage Area (PDA) (F) or Adjacent to Primary Damage Area (APDA(F))	Description
1	Comm Center/Crew Living Space[1]	PDA(F)	Large heptane spray fire[2] and 1 large wood crib[3]
2	Radio Transmitter Room	PDA(F)	Small wood crib[4]
3	Comm Center	PDA(F)	Small heptane spray fire[5]
4	Tomahawk Equipment Room	APDA(F) (horizontal spread)	Bin filled with Class A material
5	Tomahawk Equipment Room	APDA(F) (horizontal spread)	Bin filled with Class A material
6	CIC Office	APDA(F) (vertical or horizontal spread)	Bin filled with Class A material
7	Combat Systems Office	APDA(F) (vertical or horizontal spread)	Bin filled with Class A material
8	Operations Office	PDA(F) (vertical or horizontal spread)	Bin filled with Class A material
9	CSMC/Repair 8	APDA(F) (vertical spread)	Bin filled with Class A material

1 Flames from the Comm Center/Crew Living fire extended into CIC since the blast panels in the overhead was removed

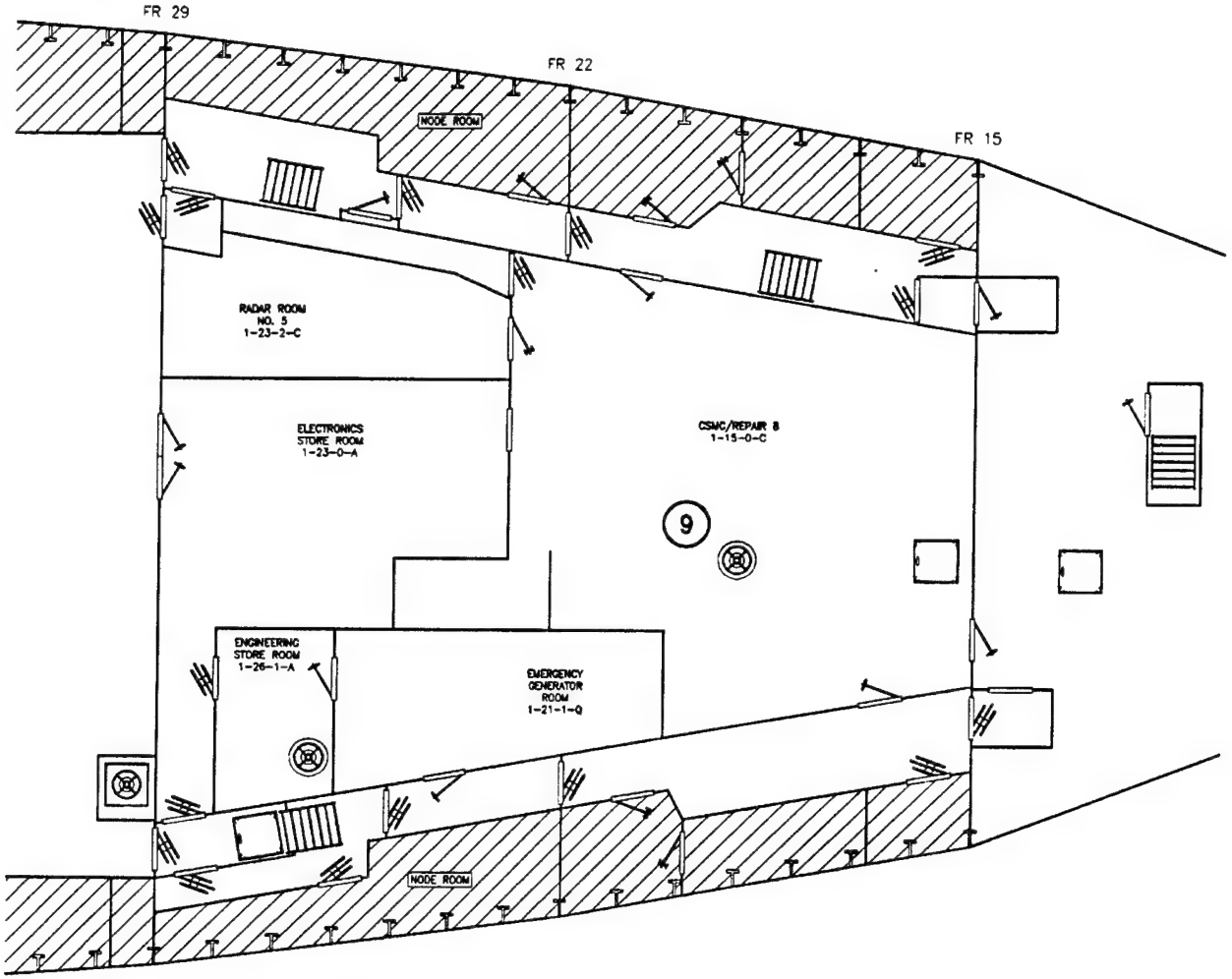
2 Large heptane spray fire, used Bete FF125 nozzle at 4.1 bar (60.0 psi)

3 Two large wood cribs, each composed of 10 rows of 1.2-m (4.0-ft) long sticks, 3.8-cm (1.5-in.) square with 10 sticks per row, supported on a metal stand approximately 0.6-m (2.0-ft) above the deck

4 Small heptane spray fire, used Bete P28 nozzle at 4.1 bar (60.0 psi)

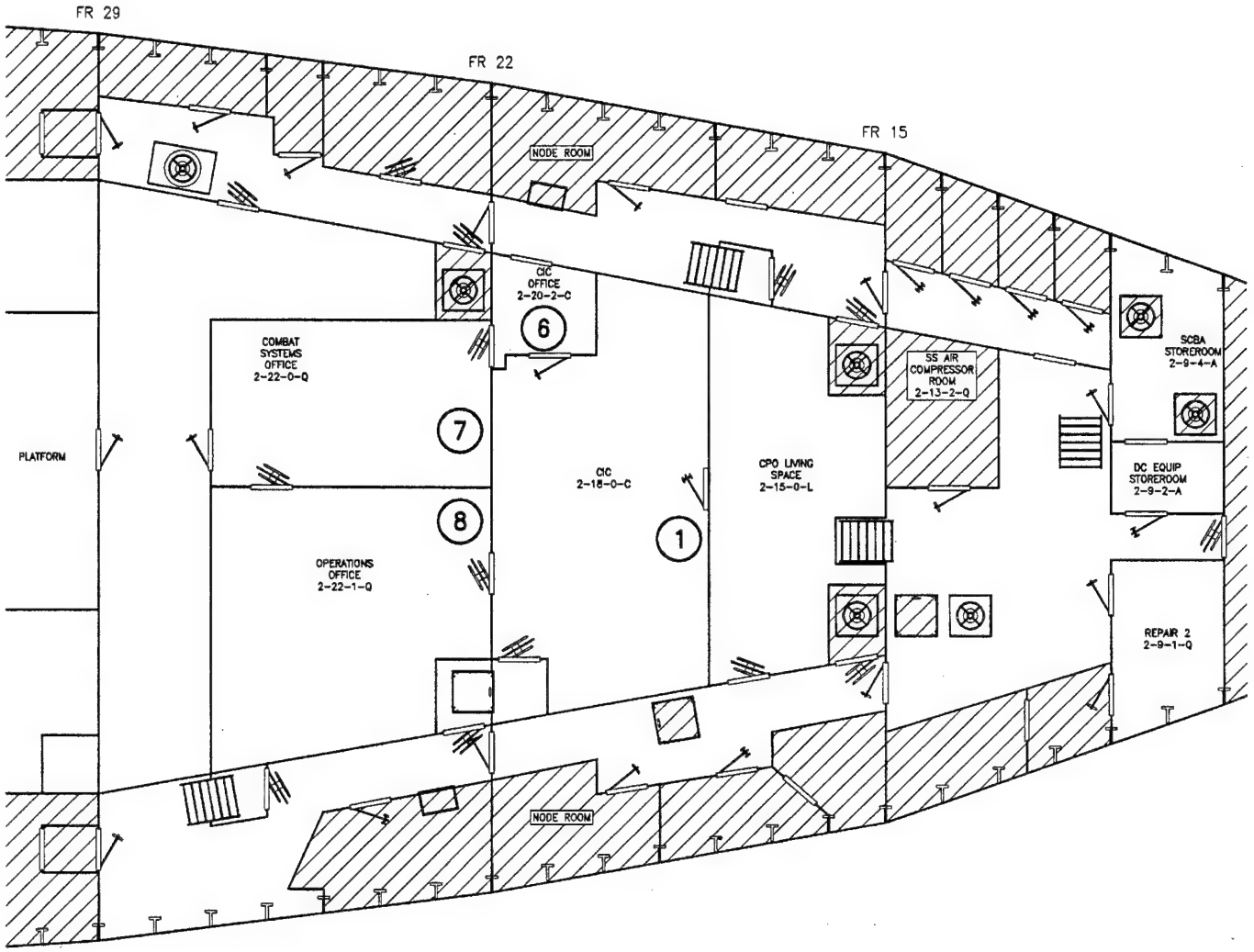
5 Small wood crib composed of 10 rows of 0.6-m (2.0-ft) long sticks, 3.8-cm (1.5-in.) square with 6 sticks per row, supported on a metal stand approximately 0.3-m (1.0-ft) above the deck

As with the approach used in the FY 00 and FY 01 DC-ARM tests, aggressive fire attacks in the PDA(F) were not incorporated. Rather, the primary focus was to prevent fire spread to APDA(F) compartments. With the assistance of the DC systems, the manning organization was expected to reduce the threat in the PDA(F) and maintain tenable conditions in the APDA(F). In order to meet these goals, indirect fire attacks were conducted using the installed PDA cooling system and other manual means.



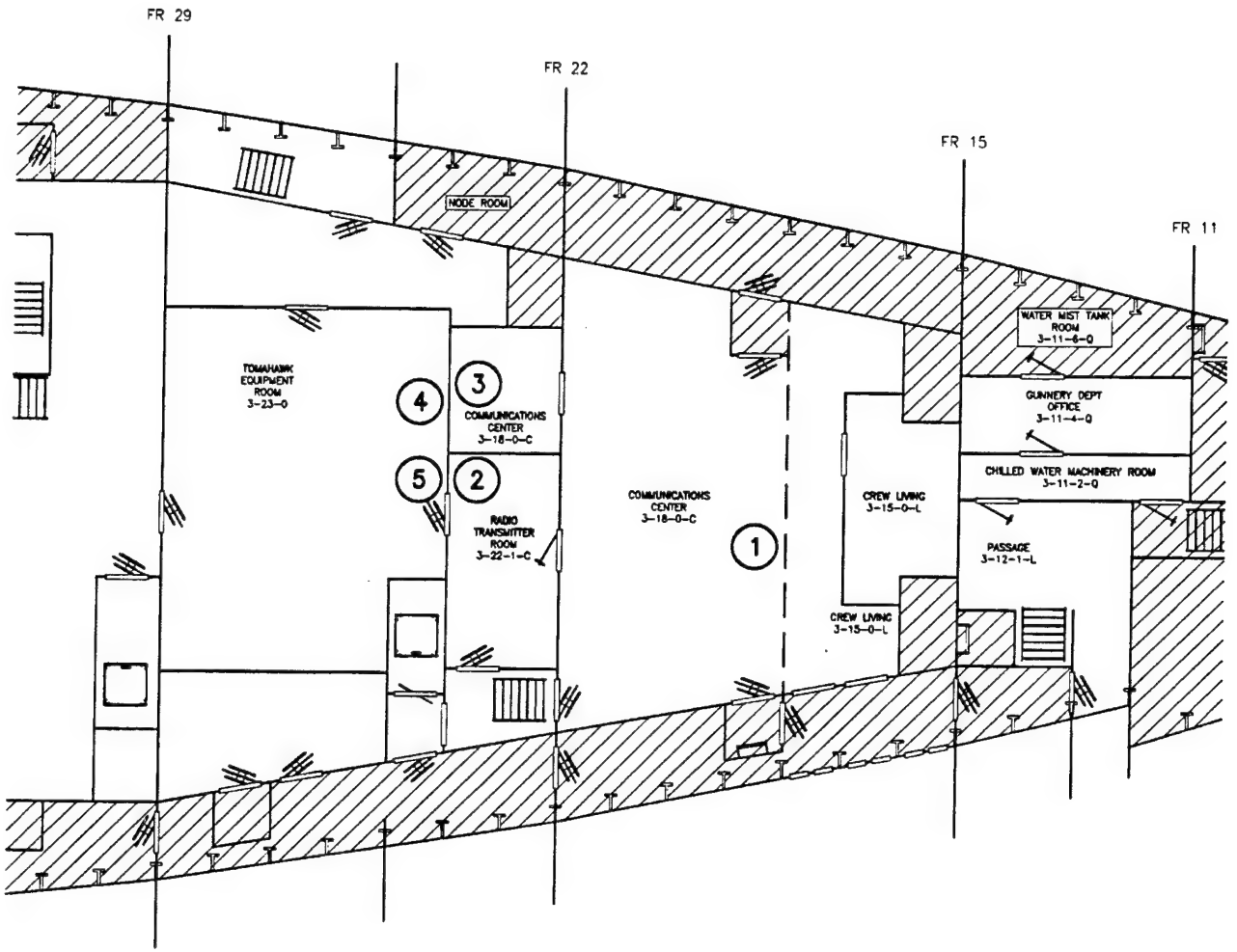
NOTE:
HATCHED AREAS ▨ ARE NOT PART OF TEST AREA.

Fig. 17 – Main deck fire locations



NOTE:
HATCHED AREAS ▨ ARE NOT PART OF TEST AREA.

Fig. 18 - Second deck fire locations



NOTE:
HATCHED AREAS ▨ ARE NOT PART OF TEST AREA.

Fig. 19 – Third deck fire locations

5.3 Setup for Combat Damage Tests

A large heptane spray fire (approximately 6.0 MW) and two large wood cribs were staged in the Comm Center/Crew Living Space. In addition, a small wood crib was staged in the Radio Transmitter Room. This crib was positioned in the aft, port corner of the Radio Transmitter Room, adjacent to Frame 24 in order to provide heating of the bulkhead. Spray fires were initiated using a small cup of heptane located near the spray. The wood crib in the Radio Transmitter Room was initiated by a small pan of heptane placed under the crib. The wood cribs in the Comm Center were initiated by the large spray fire, which was located adjacent to the cribs.

An additional heptane spray fire (approximately 400 kW) was located at Frame 24 in the Comm Center to provide localized bulkhead heating. This small spray fire was instrumental for obtaining sympathetic ignition in the Tomahawk Equipment Room.

Fire spread to APDA(F) compartments was staged to determine if containment was achieved. Fuel packages in APDA(F) compartments consisted of bins filled with excelsior, wood and paper. The bins were 0.9 m wide by 0.3 m deep by 1.2 m high (3 ft wide by 1 ft deep by 4 ft high) and were constructed of expanded metal. The bins were located where sympathetic ignition was likely. Multiple bins, with the ends adjacent to each other, were staged in some locations so that the fire could propagate between bins.

The blast may destroy sensors, pipe and ductwork located in the PDA(F) (i.e., Comm Center, AMR No. 1, Crew Living Space, Radio Transmitter Room, CIC, CPO Living, and Operations Office). During these tests, this damage translated to degradation of the suppression system, PDA cooling system, *Shadwell* sensors, and video. The level of damage to these systems varied to allow for a more thorough evaluation of the SCS logic. Damage to some of these systems was accomplished by physically removing sensors or nozzles. Other systems were damaged electronically.

A test matrix summarizing the combat damage tests is provided in Table 5. Test variables included fire locations within the PDA(F) and APDA(F), availability of suppression systems and level of sensor damage.

(0.75 in.) hose reel, directed through an existing scuttle or hatch, or a hole cut in the deck or bulkhead. The DD(X) design proposes the use of only 1.9 cm (0.75 in.) hose reels or a standard 4.0 cm (1.5 in.) hose with a vari-nozzle.

Based on previous analysis, it is likely that all accesses within the PDA(F) would be blocked [22]. Furthermore, debris such as ductwork would cover the deck. This would make it difficult for personnel to access the PDA(F) quickly. For these tests, damage to the accesses into the PDA(F) compartments was simulated by chaining them shut on the inside.

Table 5. Test Matrix for Combat Damage Test Scenarios

Test Name	PDA(F) Fire Location	APDA(F) Compartments with Potential Fire Spread	Comments
afss01[1]	• Comm Center/Crew Living, • Comm Center at FR 24 • Radio Transmitter Room	• CSMC/Repair 8[2] • CPO Living[2] • Tomahawk Equipment Room[2]	• (3) of 5 hull vents open • CPO Living part of APDA(F) • Baseline fire, no water mist
afss02[1]	• Comm Center/Crew Living, • Comm Center at FR 24 • Radio Transmitter Room	• CSMC/Repair 8[2] • Tomahawk Equipment Room[2] • Combat Systems[3] • Operations Office[3]	• Baseline fire, no water mist • All 5 vents open to weather • CPO Living part of PDA(F) • E1-15-1 and E1-15-2 fans operating at 75% • LPSS on low
afss03[1]	• Comm Center/Crew Living, • Comm Center at FR 24 • Radio Transmitter Room	• CSMC/Repair 8[2] • Tomahawk Equipment Room[2] • Combat Systems[3] • Operations Office[3]	• Baseline fire, no water mist • All 5 vents open to weather • CPO Living part of PDA(F) • E1-15-1 at 75% and E1-15-2 fans operating at 50% • LPSS on high
afss04[1]	• Comm Center/Crew Living, • Comm Center at FR 24 • Radio Transmitter Room	• CSMC/Repair 8[2] • Tomahawk Equipment Room[2] • Combat Systems[3] • Operations Office[3]	• Thermally activated nozzles installed in PDA and APDA • CPO Living part of PDA(F) • All 5 vents open to weather • Ventilation same as afss03
afss06[1]	• Comm Center/Crew Living, • Comm Center at FR 24 • Radio Transmitter Room	• CSMC/Repair 8[2] • Tomahawk Equipment Room[2] • Combat Systems[3] • Operations Office[3]	• Thermally activated nozzles installed in PDA and APDA • CPO Living part of PDA(F) • All 5 vents open to weather • Ventilation same as afss03 • Kept small spray fire in Comm Center at Frame 24 burning after sympathetic ignition occurred in Tomahawk Eqpt. Room
afss14	• Comm Center/Crew Living, • Comm Center at FR 24 • Radio Transmitter Room	• CSMC/Repair 8[2] • Tomahawk Equipment Room[2] • Small Comm Center[2] • Combat Systems[3] • Operations Office[3]	• Water mist activated by SCS • CPO Living part of PDA(F) • All 5 vents open to weather • Ventilation same as afss03 • Kept small spray fire in Comm Center at Frame 24 burning after sympathetic ignition occurred in Tomahawk Eqpt. Room

Table 5. Test Matrix for Combat Damage Test Scenarios

Test Name	PDA(F) Fire Location	APDA(F) Compartments with Potential Fire Spread	Comments
afss15	• Comm Center/Crew Living, • Comm Center at FR 24 • Radio Transmitter Room	• CSMC/Repair 8[2] • Tomahawk Equipment Room[2] • Combat Systems[3] • Operations Office[3]	• Water mist activated by SCS • CPO Living and Operations Office part of PDA(F) • All 5 vents open to weather • Ventilation same as afss03 • Kept small spray fire in Comm Center at Frame 24 burning after sympathetic ignition occurred in Tomahawk Eqpt. Room
afss16	• Comm Center/Crew Living, • Comm Center at FR 24 • Radio Transmitter Room	• CSMC/Repair 8[2] • Tomahawk Equipment Room[2] • Combat Systems[3] • Operations Office[3]	• Water mist activated by SCS • CPO Living part of PDA(F) • All 5 vents open to weather • Ventilation same as afss03 • Kept small spray fire in Comm Center at Frame 24 burning after sympathetic ignition occurred in Tomahawk Eqpt. Room
afss17	• Comm Center/Crew Living, • Comm Center at FR 24 • Radio Transmitter Room	• CSMC/Repair 8[2] • Tomahawk Equipment Room[2] • Combat Systems[3] • Operations Office[3]	• Water mist activated by SCS • CPO Living part of PDA(F) • All 5 vents open to weather • Ventilation same as afss03 • Kept small spray fire in Comm Center at Frame 24 burning after sympathetic ignition occurred in Tomahawk Eqpt. Room • No water mist in CPO Living
afss18	• Comm Center/Crew Living, • Comm Center at FR 24 • Radio Transmitter Room	• CSMC/Repair 8[2] • Tomahawk Equipment Room[2] • Combat Systems[3] • Operations Office[3]	• CPO Living and Operations Office part of PDA(F) • All 5 vents open to weather • Ventilation same as afss03 • Dog-leg fire not ignited • PDA cooling not available in Comm Center • SCS not used, water mist activated based on compartment temperatures • No water mist in Comm Center

[1] – Workup test, Supervisory Control System not used
[2] – One bin staged in compartment for sympathetic ignition
[3] – Two bins staged in compartment for sympathetic ignition

If the PDA cooling systems were unable to extinguish the fires, indirect fire attacks could be conducted from APDA(F) compartments. One approach was to use an installed 1.9 cm

6.0 TEST RESULTS

6.1 Peacetime Fire Scenarios

A total of seven tests were conducted for the peacetime fire scenarios. The following sections summarize each of these tests. Graph data is provided for selected tests. It should be noted that these graphs include the background data collected at the beginning of each test. Background data collection times varied per test. The times discussed in the following sections are the elapsed times after the start of the test (i.e., ignition of fire(s)) and exclude this background time.

6.1.1 CPO Living Fire Scenario

The peacetime fire in CPO Living consisted a wood crib, positioned in the forward, port corner of the compartment. A total of two tests (afss10 and afss11) were conducted for this peacetime scenario.

In both tests, the RRT was initially stationed on the 02 Level, outside of the test area. The Scene Leader and Primary Responders responded to the scene wearing fire retardant coveralls and flash gear (SCBAs were not used by this portion of the team). The three-person Attack Team responded to the scene wearing fire retardant coveralls and flash gear. Unlike the initial responders, this portion of the team used SCBAs.

Summary of Events - afss10

In this test, thermally activated overhead nozzles (i.e., APDA nozzles) were installed in CPO Living. Two of the three nozzles activated within 30 seconds of ignition. The remaining nozzle opened after the water mist system was reactivated.

Over three minutes passed before the Scene Leader and Primary Responders were able to find CPO Living. This delayed response was partially a result of the team not being familiar with the layout of the test spaces. When the three initial responders arrived at the CPO Living compartment, they were reluctant to enter the space because of the conditions created by the water mist system (i.e., it was difficult to breathe/see). The Scene Leader secured the water mist system, however the team was still reluctant to enter the space, so they backed out and waited for the Attack Team to arrive. Safety Team members pointed out that the water mist system should be re-activated while waiting for the Attack Team, so the Scene Leader requested re-activation of water mist.

The Attack Team arrived at CPO Living approximately seven minutes after the fire was called away. Factors contributing to this delay included personnel unfamiliarity with the test

spaces and problems with SCBA face pieces fogging. The Attack Team put their SCBAs on as soon as they were called away. During the test debrief it was discussed that the team could have waited to use breathing protection until they entered an environment where the SCBAs were needed. Waiting to use breathing protection until necessary would improve visibility and communications and would most likely result in a quicker response.

When the Attack Team arrived at the fire compartment, the Scene Leader again requested that the water mist system be secured so the team could enter the space. At this time, the fire was reported out. In this scenario the APDA (F) water mist system was able to extinguish the fire.

Summary of Events - afss11

Open APDA(F) nozzles were installed in the test space during this test. Since this test was conducted without the use of the SCS, water mist was activated when the compartment temperatures reached the activation temperature of the thermally activated nozzles. This occurred approximately one minute after the wood crib was initially ignited. Since the water mist system extinguished the fire in CPO Living during test afss10, a locker was positioned in front of the fire during test afss11. This locker acted as on obstruction and helped to reduce the amount of water that directly sprayed on the fire.

The Scene Leader and Primary Responders left the 02 Level within 30 seconds of the fire being called away and arrived at CPO Living approximately 2½ minutes later. Upon their arrival, the Scene Leader requested water mist be secured so they could assess the situation. At this time, they observed the fire and decided the fire was too large for them to handle without breathing protection. They backed out of the space and waited for the Attack Team to arrive. With the water mist system secured, temperatures in the overhead quickly increased (see Fig. 20).

The Safety Team recommended that the Scene Leader reactivate water mist until the Attack Team arrived. Water mist was reactivated less than one minute later and overhead temperatures quickly dropped to approximately 50°C (122°F). The water mist system remained on until the Attack Team was on-scene and ready to enter the space.

The Attack Team initially attempted to contain the fire using a 1.9 cm (0.75 in) hose reel. Once the fire appeared to have been contained, the team used a portable AFFF extinguisher to try to extinguish the remaining flames. After emptying the extinguisher, the fire began to grow so the team used the hose again to try to knock down some of the flames. During this time, the DCO noticed that the temperatures in the compartment were increasing; therefore, he asked the Scene Leader if water mist should be reactivated. The Scene Leader responded that water mist was not needed as the fire had been contained and was still being fought by the Attack Team. Once the fire was knocked down again, the team used a second portable extinguisher on the fire. This time they were able to fully extinguish the fire and a reflash watch was set.

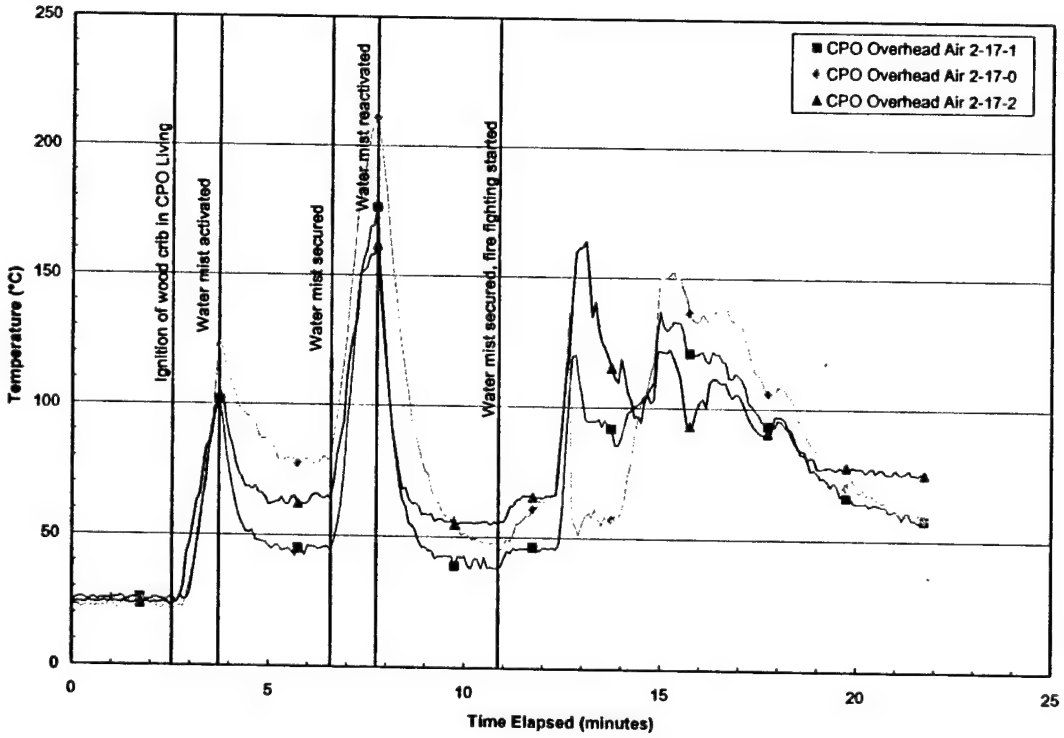


Fig. 20 – CPO Living overhead air thermocouples, afss11

6.1.2 AMR No. 1 Fire Scenario

The peacetime fire in AMR No. 1 consisted of a large diesel pan fire, a small unobstructed heptane pan fire, and two wood cribs. The obstructed pan fire and the wood cribs were ignited by the Safety Team. These fires were allowed to grow for 30-60 seconds, before the diesel pan fire was ignited by the Safety Team. The ignition of the large pan fire signified the start of the test.

As the machinery space was unmanned, activation of the water mist system was based on elevated temperatures within the space. In each test, the water mist system was activated by Test Team personnel shortly after the fire was detected. Upon activation of the water mist system, the machinery space ventilation system (Limited Protection Exhaust System (LPES)) was secured. Ventilation was reactivated at the request of on-scene personnel, typically before they entered the space. The RRT was called away by the DC Watch stander over the 1MC and the Primary Responders and Scene Leader responded to the scene. The entire RRT responded to the machinery space in fire retardant coveralls, flash gear and SCBAs.

Summary of Events – afss05

For scenario afss05, when the Primary Responders and Scene Leader arrived to the machinery space, they were reluctant to enter the space because of conditions created by the water mist system. They decided to wait for the Attack Team to arrive. While waiting for the Attack Team to arrive, the Scene Leader requested that the ventilation system be reactivated.

The diesel pan fire and wood crib located on the fourth deck were extinguished by the water mist system. The remaining fires (wood crib on the fifth deck and the obstructed pan fire) were extinguished by the Attack Team.

Summary of Events – afss07

When the Primary Responders and Scene Leader responded to the scene, the ventilation system was started (LPES) and the team entered the space. The diesel pan fire and the wood crib on the fourth deck were extinguished by the water mist system. While the water mist system was still on, the Primary Responders extinguished the obstructed pan fire using a portable extinguisher. The team then requested that the water mist system be secured. Securing water mist is counter to the doctrine and tactics identified in NSTM [29] and changes proposed by NAVSEA [30]. These documents contain guidelines for machinery space water mist systems, which include securing water mist only after the fire space has been investigated and all fires have been extinguished.

After the water mist system had been secured, the Primary Responders found the wood crib fire on the fifth deck and extinguished it with a portable extinguisher. A few minutes later the wood crib on the fifth deck reflashed. The fire was again extinguished using a portable extinguisher and the reflash watch was set by the Primary Responders.

6.1.3 Radio Transmitter Room Fire Scenario

The peacetime fire in the Radio Transmitter Room consisted of four sheets of fiberboard positioned on the bulkheads in this compartment to create flashover conditions in the space. To create a longer duration fire, sheets of plywood were positioned behind the fiberboard during tests afss09 and afss13. Bins were positioned in the Comm Center, Tomahawk Equipment Room, Combat Systems Office and Operations Office to determine if fire spread to these adjacent spaces was possible.

For this scenario, the water mist system in the Radio Transmitter Room was disabled to simulate a system failure. This resulted in a fire that required the DC organization to "flex up" from the six person RRT to the entire Repair Locker Team. Open water mist nozzles were installed in adjacent spaces during test afss13. Water mist was activated in these spaces when the compartment temperatures reached approximately 79°C (174°F) (i.e., the activation temperature of the thermally activated nozzles).

Summary of Events – afss08

For this scenario a six person RRT was available. This test was conducted to determine if the six-person RRT was adequate to respond to this scenario. As such, the entire Repair Locker was not staffed. The fire was determined to be too large for the RRT to handle, therefore the DC organization was not permitted to respond to the fire.

Summary of Events – afss09

When the fire was called away by the DCO, the Casualty Coordinator dispatched the investigators from the Repair Locker. The investigators went down starboard passageway on the second deck and reported that there were no apparent casualties on the second deck and then continued their investigation.

Approximately 9 minutes after ignition of the fire in the Radio Transmitter Room, the bin in the Operations Office sympathetically ignited. This fire was still burning when the investigators entered the space. The fire was reported by the investigators and was extinguished using a portable AFFF extinguisher within a few minutes of ignition.

The Support Team was dispatched by the Casualty Coordinator to the Radio Transmitter Room. The Support Team encountered flames on the starboard side, second deck coming out of the ladder well leading to the Radio Transmitter Room. They tried to use the 1.9 cm (0.75 in) hose to knock down the fire, but were not effective. The Support Team then went to CIC, to try to access the Operations Office. From this space, the Support Team was going to use the fire drill to try to extinguish the Radio Transmitter Room fire from above. The door to the Operations Office was stuck shut (because of heat). Since the team could not open the door to Operations Office, the Support Team backed out of the space.

Approximately 12 minutes after the fire in the Radio Transmitter Room was ignited, the bin in the Tomahawk Equipment Room ignited. At this time temperatures on the unexposed side of the bulkhead reached approximately 250°C (482°F), see Fig. 21. One minute later the bin in the Combat Systems Office ignited. The investigators continued their investigation and found a fire in the Tomahawk Equipment Room. They extinguished this fire with a portable extinguisher.

The Attack Team was eventually required to extinguisher the fire in the Radio Transmitter Room. The team used the 1.9 cm (0.75 in) hose, located on the second deck, starboard side, to extinguish this fire.

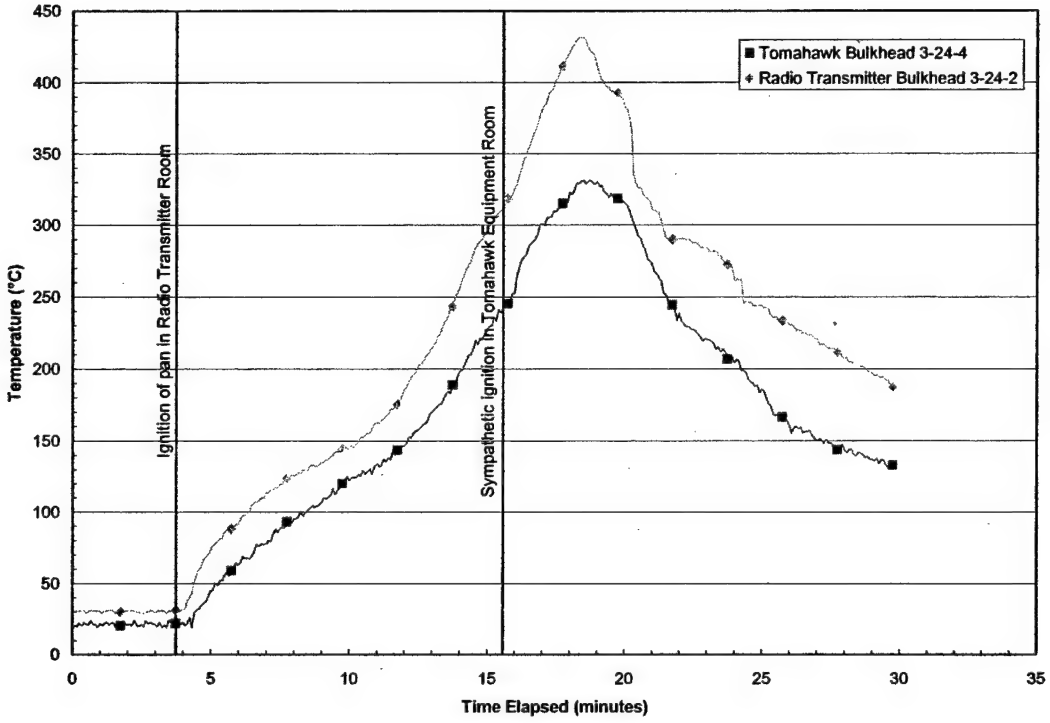


Fig. 21 – Tomahawk Equipment Room/Radio Transmitter Room bulkhead thermocouples, afss 09

Summary of Events – afss13

When the fire was called away by the DCO, the initial six person RRT responded to the fire. The Scene Leader and Primary Responders were the first to respond. The Scene Leader reported that the fire was out of control and determined that the full Repair Party was needed for this fire. During this test, observations were made that many of the test participants were unfamiliar with using the SCBAs. This resulted in delays dressing out (i.e., fire fighting ensembles and breathing apparatus). In this test it took more than 8 minutes for the team to fully dress out.

Overhead temperatures in the Comm Center exceeded the activation temperature for the water mist nozzles within 1½ minutes of ignition of the fire in the Radio Transmitter Room. The test team attempted to activate water mist in this space. Problems were experienced with the solenoid valve for the nozzles serving this space, resulting in a delayed response from the water mist system. Water mist was actually activated almost 5½ minutes later.

The bin in the Operations Office ignited approximately 8 minutes after primary fire ignition. Water mist was activated by the test team less than one minute later. Ten minutes after ignition the bin in the Combat Systems Office ignited. Water mist was immediately activated in this space based on the elevated temperatures in the compartment. At 14 minutes, the bin in the Tomahawk Equipment Room ignited. Using video available in the Control Room, the DCO observed this fire and activated water mist.

With the Attack Team in route to fight the fire in the Radio Transmitter Room, the DCO dispatched the Support Team to set fire boundaries. The Attack Team was reported to be fighting the fire in the Radio Transmitter Room, 17½ minutes after ignition. The DCO then requested that the Backup Attack Team set a vertical fire boundary on the deck in CIC.

Approximately 19½ minutes after the fire was initially ignited, the fire in the Radio Transmitter Room was reported out. Using video available in the Control Room, the DCO observed that the fire was out in the Tomahawk Equipment Room and secured water mist in this compartment. The Support Team was then dispatched by the DCO to confirm that the fires in this space had been extinguished. All fires were reported out 21½ minutes after the test was started.

6.2 Combat Damage Fire Scenarios

6.2.1 Workup Tests

A total of five workup tests were conducted for the combat damage fire scenarios. These tests were conducted without the use of the SCS and without a DC response. These tests served as workup tests conducted to evaluate fire sizes for the actual tests. These workup tests were also conducted so a preliminary evaluation of the PDA cooling system, which has been proposed to include thermally activated nozzles, could be prepared. Tests afss04 and afss06 incorporated the use thermally activated nozzles, all other tests were conducted without the use of water mist or with open nozzles.

Workup Tests Conducted without the Involvement of Water Mist

Tests afss01, afss02, and afss03 were conducted without the use of water mist. These tests were conducted to develop the fire conditions needed for the combat damage fire scenarios. In test afss01, three of the five hull vent openings were left open, while the remaining two vents were closed. The PDA(F) included the Comm Center/Crew Living, CIC, and the Radio Transmitter Room. The CPO Living space was part of the APDA(F). Potential sympathetic ignition locations included CPO Living, CSMC/Repair 8 and the Tomahawk Equipment Room; one bin was positioned in each of these spaces. The bins in CPO Living and Tomahawk Equipment Room ignited during this test. The wood cribs in the Comm Center took almost 7 minutes to become involved. After the test was secured, the Test Team discovered that the E1-15-1 and E1-15-2 fans, which were used to supply air to the fire, were not actually on. This was adjusted for the remaining tests.

In test afss02, the PDA varied from afss01 as CPO Living was part of the PDA(F). As such the door between CIC and CPO Living was kept open and the deck openings between CPO Living and the Comm Center were left open. Both fans E1-15-1 and E1-15-2 were operated at 75%. In addition, CPS was activated and the Limited Protection Supply System (LPSS) was operated on low. The LPSS provided additional ventilation for the wood crib fire in the Radio Transmitter Room. Slightly lower temperatures were observed throughout the test area and sympathetic ignition only occurred in the Tomahawk Equipment Room.

For test afss03, the PDA was identical to that used in afss02. Ventilation conditions were similar, with the following exceptions: E1-15-1 was operated at 75%, while E1-15-2 was operated at 50%, LPSS was operated on high and the damper to AMR No. 1 was closed. Higher temperatures were observed throughout, particularly in the Radio Transmitter Room. Sympathetic ignition occurred in the Tomahawk Equipment Room and the Combat System Office. This is the baseline test that will be used for comparison purposes.

Workup Tests Conducted with Thermally Activated Water Mist Nozzles

Tests afss04 and afss06 were the combat damage tests conducted with the thermally activated nozzles. For test afss04 the PDA(F) and ventilation conditions were identical to those used during test afss03. The test started with the ignition of the spray fires in the Comm Center, even though the fire in the Radio Transmitter Room was actually ignited approximately 30 seconds earlier. The water mist nozzles in the Comm Center opened within 13 seconds of ignition. The main spray fire was extinguished 5 minutes, 40 seconds later.

Sympathetic ignition occurred in the Tomahawk Equipment Room, 2 minutes 40 seconds after the start of the test. Water mist was activated 22 seconds later and the fire was extinguished. The bin in the Combat Systems Office also ignited during this test. Water mist was activated and this fire was extinguished.

For test afss06, the PDA and ventilation conditions were identical to those used during afss03 and afss04. The difference between tests afss04 and afss06 was that the small spray fire in the Comm Center was kept burning after sympathetic ignition occurred in the Tomahawk Equipment Room. As with the other tests, the start of the test was signified by the ignition of the spray fires in the Comm Center.

Water mist was activated in CPO Living approximately 45 seconds after the start of the test. At 3 minutes, 22 seconds the water mist system was activated in the Tomahawk Equipment Room. The bin ignited approximately 14 seconds later. The Safety Team reported that this fire was extinguished less than one minute after the water mist was activated.

Problems were experienced with the solenoid valve in the Comm Center. This resulted in a delayed activation of water mist in this compartment. While the thermal element for these nozzles actually opened within seconds of ignition, water mist was not actually activated until 5 minutes, 12 seconds after the start of the test. Although not planned, the delay in activation is more representative of the expected response time under combat damage conditions. At 10 minutes, 43 seconds the bin in the Combat Systems Office ignited. The water mist system was activated 11 seconds later. The fire in this space was extinguished at 11 minutes, 56 seconds.

The main spray fire in the Comm Center was not extinguished by the water mist system. The heptane for the spray fire ran out before the fire was extinguished. Therefore the fire was secured by the test team and the test was completed.

6.2.2 Fire Scenario afss14

For test afss14, the PDA(F) consisted of the Comm Center, Crew Living, Radio Transmitter Room on the third deck and CIC and CPO Living on the second deck. Bins were positioned in APDA(F) compartments, which included the Combat Systems Office, Tomahawk Equipment Room, CSMC/Repair 8, and the Operations Office.

While the wood crib in the Radio Transmitter Room was the first fire ignited by the Safety Team, the start of the test was actually signified by the ignition of the spray fires in the Comm Center. The Radio Transmitter Room fire was ignited almost 8½ minutes before the spray fires were ignited in the Comm Center. The Radio Transmitter Room fire was ignited much too early, as was later determined by the Test Team. For all other tests the wood crib in the Radio Transmitter Room was ignited after the Comm Center spray fires were ignited.

Due to the early ignition of the Radio Transmitter Room, the SCS experienced problems correctly identifying the PDA(F). As such the CPO Living compartment was identified as an APDA(F) space. Within 10 seconds of the start of the test, the SCS attempted to activate the APDA(F) water mist system in this compartment. Because CPO Living was intended to be a PDA(F) compartment, APDA(F) water mist was unavailable during this test. The SCS was not able to determine that the APDA(F) water mist was not operating and was therefore unable to activate the PDA(F) nozzles.

The SCS reported fires in the Comm Center, CPO Living, Radio Transmitter Room and CIC within 40 seconds of the start of the test. At 1 minute, 4 seconds, the water mist system in the Radar Room on the main deck was activated by the SCS due to elevated temperatures (approaching 80°C (176°F) in this space. When water mist was activated, temperatures in the space quickly dropped below 50°C (122°F). The SCS secured water mist at 4 minutes, 15 seconds.

The bin in the Combat Systems Office ignited approximately 1½ minutes after the start of the test. The DCO observed this fire using video of this space and reported the fire to the Casualty Coordinator. Water mist was not activated in this compartment until nearly 8½ minutes later.

At 2 minutes, 46 seconds the SCS activated the water mist system in the Tomahawk Equipment Room in the pulsing mode. A few seconds later the bin in this space ignited. The fire was quickly extinguished and the water mist system continued to cycle on and off. The water mist system was activated in a cycling mode in the Operations Office at 4 minutes, 37 seconds. Water mist was activated by SCS in this space because of the rate the temperatures were increasing.

The PDA water mist system was activated in the CPO Living at 8 minutes, 35 seconds. With the exception of the area directly above the Comm Center wood cribs, overhead temperatures quickly decreased once water mist was activated (see Fig. 22).

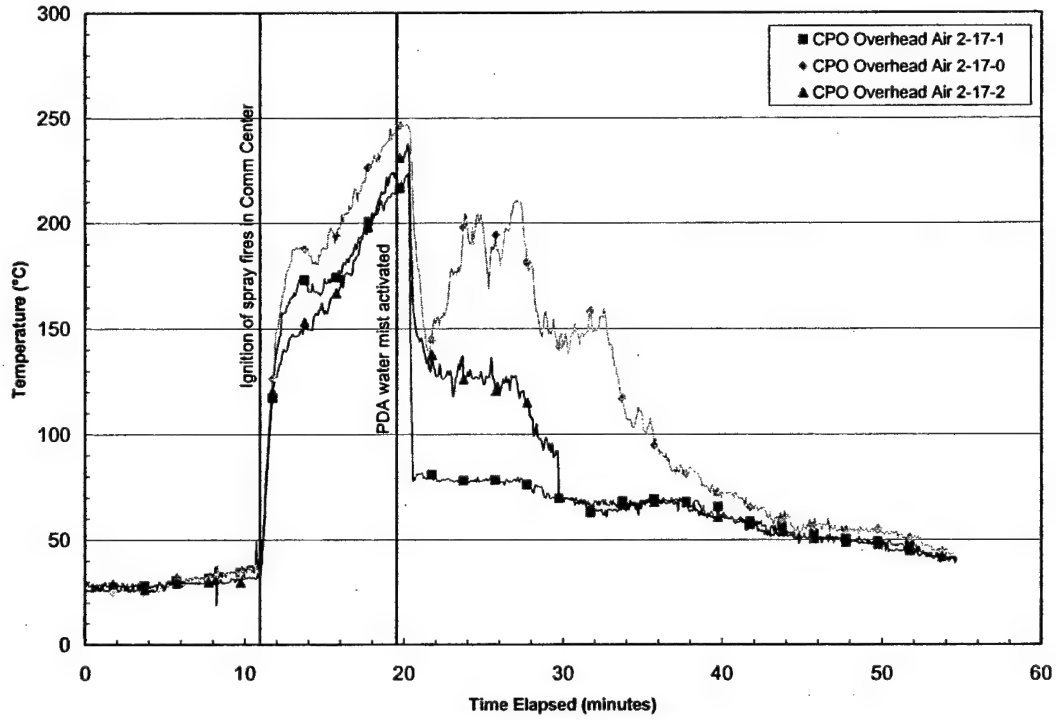


Fig. 22 –CPO Living overhead air thermocouples, afss14

Approximately 3 minutes after the start of the test the DCO requested that the Casualty Coordinator set manual fire boundaries in the starboard passageway, second deck. The Support Team was dispatched at 4 minutes, 40 seconds to set fire boundaries. At 6 minutes, 35 seconds the DCO requested a fire boundary for the bulkhead at Frame 15. An additional fire boundary was requested by the DCO for the port passageway on the second deck at 8½ minutes. The boundaries were reported set at 13 minutes, 27 seconds, approximately 10½ minutes after the DCO ordered the first boundary.

At 14 minutes, 50 seconds, the DCO dispatched Attack Team #1 to CSMC/Repair 8 to conduct indirect cooling through scuttle 1-18-0. At 21 minutes, 28 seconds the Attack Team Leader requested that the DCO secure water mist in CIC. It is believed that the team leader actually wanted water mist secured in CSMC, since water mist was not operational in CIC. Approximately 25 minutes after the start of the test, the indirect attack was reported to be in progress.

The DCO ordered the ART to investigate the access to the Comm Center approximately 19½ minutes after the start of the test. At 27 minutes, 10 seconds the DCO requested that the Support Team gain access to the Comm Center using the exothermic torch, while the indirect attack was being conducted. Access to the Comm Center was made at 38 minutes, 2 seconds and the DCO directed Attack Team #2 to conduct a direct attack of the remaining fires in the Comm Center. At this time overhead temperatures had dropped to less than 200°C (392°F) and the wood cribs had mostly been consumed. The fire in this space was reported out at 39 minutes, 25 seconds.

At 27 minutes, 54 seconds the DCO requested that the ART investigate the Tomahawk Equipment Room for fire. The team reported that the aft door (QAWTD 3-29-1) to this space was jammed, but not hot. The DCO directed the team to access the Tomahawk Equipment Room through door 3-24-1. Due to time limitations, the team did not actually enter this space before the test was secured.

6.2.3 Fire Scenario afss15

For scenario afss15, the PDA (F) included the Comm Center, Crew Living, Radio Transmitter Room, CPO Living, CIC and the Operations Office. PDA cooling was available in the Operations Office, CPO Living and the Comm Center; the APDA water mist system was available in the Combat Systems Office and Tomahawk Equipment Room. The test began with the ignition of the spray fires in the Comm Center, the wood crib in the Radio Transmitter Room was ignited approximately 1½ minutes later.

The SCS identified the PDA(F) within 30 seconds of the start of the test. The Operations Office was not included in the PDA(F) identified by the SCS. This was later determined to be a correct identification by the system. As discussed in Section 3.7, the SCS used real sensor data and the damaged sensor data to identify PDA(F) spaces. For this test, the intent was to include the Operations Office as a PDA(F) space by simulating damaged data for this compartment. After the test was completed, the test team discovered that the SCS was actually receiving the correct data for the sensors in the Operations Office. The temperatures in the compartment were not initially hot enough for the SCS to classify the space as part of the PDA(F).

Approximately 2 minutes after ignition of the spray fires, the SCS reported a fire in the Operations Office due to the elevated temperatures in this space (see Fig. 23). The system identified that a boundary was needed for the Operations Office. At this time, the water mist function of the supervisory control system did not appear to be functional, therefore the system was reset. After the system was reset, the SCS attempted to activate the APDA nozzles in the Operations Office (5 minutes, 31 seconds after ignition). Since this system was intended to be classified as a PDA(F) compartment, the APDA system was not operational and water mist was not activated in this space.

Approximately 5 minutes after ignition, the bin in the Tomahawk Equipment Room ignited. Water mist was activated 30 seconds later. The SCS activated water mist in the Comm Center 9½ minutes after the ignition of the spray fire in this space. These fires were extinguished less than one minute later. Water mist was activated in the Combat Systems Office at 10 minutes, 20 seconds. The system was operating in a cycling mode in the Combat Systems Office and the Tomahawk Equipment Room. Approximately two minutes after the Combat Systems Office water mist system was activated, the bin ignited, however the water mist system was able to quickly extinguish this fire.

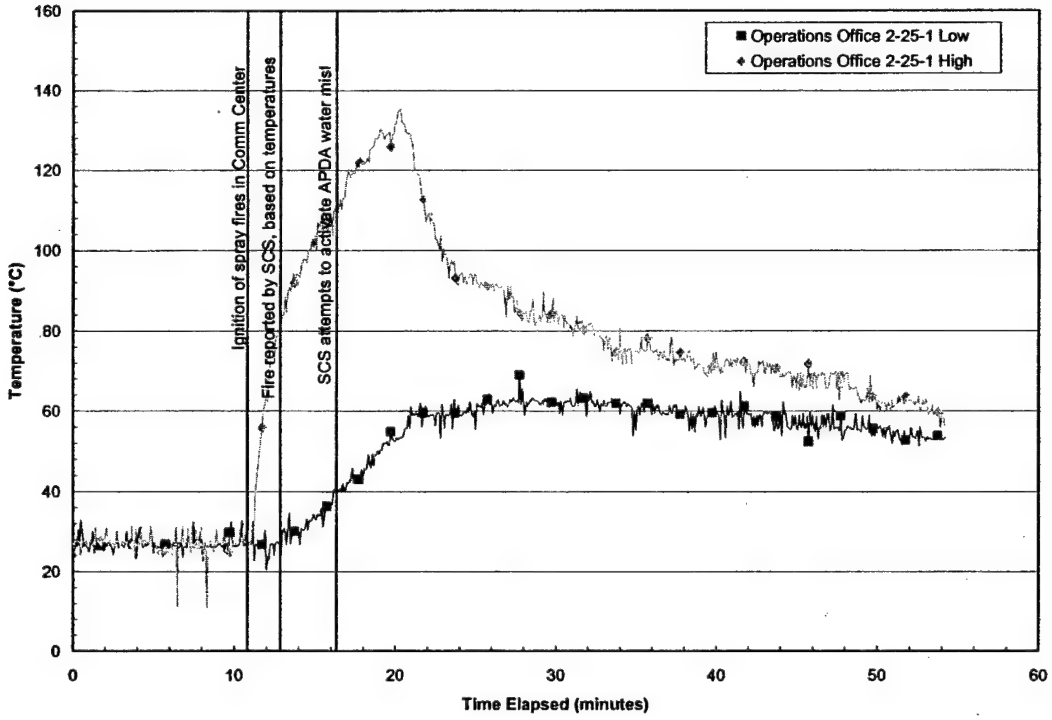


Fig. 23 – Operations Office high low thermocouples, afss15

Almost 7 minutes after the start of the test, the DCO requested that the Casualty Coordinator dispatch a team to set manual fire boundaries on the 2nd deck, port and starboard sides between Frames 15-22. The fire boundary on the starboard side was reported set 5 minutes, 40 seconds later, while the port side boundary was reported set 7 minutes, 12 seconds after the initial order to set boundaries had been given. Sixteen minutes, 9 seconds after the start of the test, the DCO ordered the fire boundary on the starboard side be extended to Frame 29 due to the elevated temperatures and lack of water mist in the Operations Office. This boundary was reported set more than 16 minutes later.

For this test the ART was divided into two (2) three person investigation teams (ART #1 and ART #2). Approximately 3 minutes after the start of the test, the DCO dispatched an investigation team to investigate the starboard access to CIC. Nearly 14 minutes after the start of the evolution, the DCO dispatched ART #2 to investigate the Tomahawk Equipment Room on the third deck. The team reported that the water mist system was still operating in this space and the fire was still burning.

At 14 minutes, 36 seconds, ART #1 reported that there was no access to the CIC compartment. The DCO then requested that they investigate the starboard access to the Comm Center. Nearly 6 minutes later, the DCO had not been updated on the status of the access to the Comm Center. A report was made that the door to the Comm Center was partially jammed and that water mist was still operating in this space. At 37 minutes, 18 seconds a report was made that Attack Team #1 was fighting the fire in the Comm Center. Before this report, the DCO had not been informed that access had been made and that the Attack Team was fighting the fire.

At 27 minutes, 30 seconds the DCO dispatched Attack Team #2 to the Operations Office to extinguish the fire that had been detected by the SCS. Although there was no fire in this space, the door between the Operations Office and CIC was open. This caused elevated temperatures in this space, such that a fire was detected by the SCS. The DCO dispatched ART #1 at 32 minutes, 33 seconds, to investigate the port side access to the Operations Office, which was jammed.

A Class A fire was reported in the Radio Transmitter Room at 21½ minutes after ignition (it is unclear who made this report). The DCO recommended that the Casualty Coordinator dispatch Attack Team #1 to the Radio Transmitter Room, through the Tomahawk Equipment Room. No further reports were made regarding the Radio Transmitter Room until the fire in this space was reported out approximately 38 minutes after the start of the test. At 40 minutes, 58 seconds all fires on the third deck were reported out and the test was secured.

6.2.4 Fire Scenario afss16

The PDA(F) included the Comm Center, Crew Living, Radio Transmitter Room, CPO Living and CIC for fire scenario afss16. For this fire scenario, PDA cooling was available in the Comm Center and CPO Living, while APDA nozzles were installed in the Operations Office, Combat Systems Office, and Tomahawk Equipment Room.

The test began with the ignition of the spray fires in the Comm Center. The Safety Team ignited the wood crib in the Radio Transmitter Room within 30 seconds of the start of the test. The SCS immediately activated water mist in CPO Living and attempted to activate water mist in the Comm Center. Problems were experienced with getting the solenoid valve for the Comm Center to open, therefore the test team attempted to cycle this valve in order to get it to open. The valve finally opened at 7 minutes, 41 seconds. The fire was extinguished less than 2 minutes later (9 minutes, 5 seconds after the fire was ignited).

The SCS identified the PDA(F) within 35 seconds of ignition. Approximately 3 minutes after ignition, the DCO dispatched ART #1 to investigate CSMC/Repair 8. At 7 minutes, 40 seconds, the DCO requested that manual fire boundaries set in the port and starboard passageways on the second deck. The DCO extended manual fire boundaries to include the boundary at Frame 15, approximately 1½ minutes later (9 minutes, 10 seconds after ignition). The boundaries on the port and starboard side were reported set at 11 minutes, 11 seconds. The boundary at Frame 15 was reported set at 14 minutes, 16 seconds.

Sympathetic ignition occurred in the Tomahawk Equipment Room at 6 minutes, 18 seconds and water mist was activated (cycling on and off) by SCS less than 10 seconds later. At 8 minutes, 42 seconds the DCO dispatched ART #2 to investigate the Tomahawk Equipment Room. At 18 minutes, 9 seconds ART #2 reported that the water mist system was on in the Tomahawk Equipment Room and they were unable to conduct their investigation. They requested that the water mist system be secured. Water mist was also activated in the Operations Office.

The DCO requested that ART #1 investigate the access to the Comm Center. After the second deck fire boundaries had been set, the Casualty Coordinator reported that the accesses to CPO Living and CIC were hot and jammed. The access to the Radio Transmitter Room was reported jammed, and a partially jammed door to the Comm Center was also reported.

Approximately 15 minutes after ignition, the DCO dispatched Attack Team #1 to CSMC to conduct indirect cooling of CIC and CPO Living. At 19 minutes, 40 seconds the indirect attack was reported to be in progress. Attack Team #2 reported the fire in the Comm Center appeared to be out and requested that the Support Team be dispatched to provide access to the Comm Center. The team was in route at 23 minutes, 38 seconds. At this time the spray fire in the Comm Center had been extinguished, but the wood cribs in the Comm Center and Radio Transmitter Room were still burning.

At 26 minutes, 20 seconds the Casualty Coordinator requested that the water mist system be secured in the Comm Center, however access to the Comm Center had not been gained. The DCO waited to secure water mist until the Support Team provided access to the Comm Center. The DCO requested that Attack Team #2 fight the fire in the Comm Center. At 30 minutes, 20 seconds the fire in the Comm Center was reported out and the reflash watch was set. The DCO then requested that the Attack Team investigate the Radio Transmitter Room. The team extinguished the fire and reported it out approximately 33 minutes after the start of the test.

6.2.5 Fire Scenario afss17

The PDA(F) included the Comm Center, Crew Living, Radio Transmitter Room, CPO Living and CIC for fire scenario afss17. For this fire scenario, PDA cooling was available in the Comm Center, while APDA nozzles were installed in the Operations Office, Combat Systems Office, and Tomahawk Equipment Room.

The test began with the ignition of the spray fires in the Comm Center. The Safety Team ignited the wood crib in the Radio Transmitter Room within 45 seconds of the start of the test. The SCS identified the PDA(F) within 30 seconds of ignition and water mist was activated in the Comm Center. The SCS attempted to activate water mist in CPO Living, however water mist was unavailable in this compartment. The water mist system extinguished the spray fire in the Comm Center within 2½ minutes of ignition.

Due to a shortage in personnel, only one group of investigators was used during this test. The DCO dispatched this team to investigate the access to the CIC compartment on the starboard side. Reports were made that the doors to the CIC and CPO Living were jammed. The door to the Comm Center was reported to be partially jammed. The Support Team was dispatched to investigate the door to the Comm Center.

Boundaries were set on the second deck within 6 minutes, 40 seconds of the start of test. The DCO requested that manual fire boundaries be extended to include Frame 15, outside of Repair 2. This boundary was reported set at the end of the test, more than 24 minutes after the ignition of the spray fires.

The bin in Combat System Office ignited at 8 minutes, 35 seconds. Using the available video of this space, the DCO observed this fire. Water mist was activated approximately 3 minutes later. Prior to this, water mist was activated in the Operations Office and Tomahawk Equipment Room. For all spaces, water mist operated in a mode where the system was cycled on and off in different intervals depending on the temperature of the space. While bulkhead temperatures in the Tomahawk Equipment Room were high enough to cause ignition of combustibles against the bulkhead, it should be noted that the bin in this space was moved away from the bulkhead by the investigators.

Due to elevated temperatures in the Radar Room, the SCS detected a fire in this space. Water mist was activated in this space approximately 8½ minutes after the start of the test. At 18 minutes, 37 seconds the DCO dispatched the investigators to check the Radar Room on the main deck. Approximately 3½ minutes later, the investigators reported that there was no fire in the Radar Room.

Access to the Comm Center was made by the Support Team using the exothermic torch. At this time, the Casualty Coordinator requested that the water mist system in the Comm Center be secured as the Attack Team was preparing to enter the space. At 18 minutes, 47 seconds the fire in the Radio Transmitter Room was found by the Attack Team. This fire was reported to the DCO and the Attack Team began fighting the fire. The DCO requested the status of the fire in the Comm Center, as he had not been informed that this fire was out. The Casualty Coordinator reported that this fire was out. At 20 minutes, 15 seconds a report was made that the fire in the Radio Transmitter Room had been extinguished. Approximately 23 minutes after the start of test, all fires were reported out and the test was secured.

7.0 CONCLUSIONS

This is the preliminary test report analyzing the DD(X) CONOPS for DC manning and PDA(F) cooling. These tests were conducted in May 2003 on the ex-USS *Shadwell*. A variety of peacetime and combat damage fire scenarios were evaluated as part of this test series. This report contains a brief summary of the events for each test. A more detailed report will be prepared to further analyze the results of these tests. The following summarizes the preliminary conclusions for these tests.

- ***A properly trained damage control team, familiar with the layout of the DD(X) is essential for optimum DC response.*** For this test series, unlike DC-ARM, many of these tests were conducted using different fleet personnel. Often participants were unfamiliar with the spaces resulting in delays in response. This impacted performance and should be considered when evaluating the results of these tests.

- Test participants were unfamiliar and often times had difficulty operating the SCBAs. Since the DC organization will be comprised of fewer members, it is essential that DC training be improved.

- ***Guidance on when to secure water mist should be developed.*** During some tests, the test participants would secure water mist early on in the evolution – to improve visibility or because of steam that made conditions in the space uncomfortable. This was observed during many of the peacetime fire scenarios.

  In test afss11, the Scene Leader and Primary Responders secured water mist in order to assess the situation. As shown in Fig. 21, once water mist was secured, temperatures in the CPO Living compartment quickly increased and the team backed out of the space to wait for the Attack Team. The Safety Team recommended that the water mist system be reactivated until the Attack Team arrived to extinguish the fire. The system was reactivated and temperatures dropped. The water mist system was again secured when the Attack Team began to extinguish the fire.

  In addition to providing guidance on when to secure water mist, adequate training should also be conducted to familiarize the fleet with the conditions created by water mist in a fire environment.

- ***The need for modes of operation for the DD(X) PDA(F) and APDA(F) water mist systems should be analyzed.*** As discussed in Section 3.7, the supervisory control system operated water mist in two primary modes: Fire Suppression (FS) Mode and Boundary Cooling (BC) Mode. These modes of operation were the same as those used in DC-ARM [5]. Additional testing should be conducted to optimize the water mist system.

- ***PDA cooling using sidewall water mist nozzles has been shown to be effective in reducing temperatures and suppressing the fire.*** For the tests where the sidewall water mist system was available in the PDA, the spray fires were quickly extinguished and temperatures in the space were reduced. While the obstructed wood cribs in this space were not always extinguished, temperatures in the compartment were significantly reduced.

  It is important to note that the fire scenarios conducted during this test series did not create a challenging scenario for the PDA cooling system. There were limited obstructions and the distance between nozzles and fire were small. Recent tests conducted at the Chesapeake Bay Detachment (CBD) demonstrated that the low pressure, AM-18 water mist nozzle was only effective under optimum conditions (i.e., limited obstructions and all nozzles operating) [17].

- ***The selection of thermally activated nozzles should be further evaluated.*** While the thermally activated nozzles worked well to extinguish fires in various compartments, it is important to consider that early activation of water mist in adjacent compartments may be desired to prevent fire spread. As currently configured, the SCS activates water mist in adjacent compartments to prevent fire spread at lower temperatures than those used by the thermally activated nozzles. In addition, decisions may be made by the DCO to activate water mist in

compartments where temperatures have not reached the activation temperature of the thermally activated nozzle. If thermally activated nozzles were installed this could not be accomplished.

- ***Investigators are an essential part of the DC organization.*** This was a lesson learned during the DC-ARM series of tests and was also observed during these tests. When the investigators were confused or lacked training, it was difficult for the DCO and Casualty Coordinator to have a clear understanding of the overall picture.

- ***Communications have been and still are a problem.*** Wire Free Communications (WIFCOM) were used by the ART/BDAT to communicate with the DCO and by the Attack Teams and Support Teams to communicate with the Casualty Coordinator. As observed during previous testing on the ex-USS Shadwell, the WIFCOM system was not always reliable. Delays in investigations and other actions resulted because teams had difficulty transmitting and receiving information.

  It should be noted that communications problems are not unique to the ex-USS Shadwell. Consideration should be given to the types and redundancy of the communications systems for the DD(X). The redundancy provided by sound powered phones should be considered.

The final test report will contain a more detailed analysis. The following summarizes some of the issues that will included in the final report:

- Conduct detail analysis comparing the results of each peacetime and combat damage test with the measures of performance.

- Evaluate impact of smoke ejection system.

- Provide detailed timelines and test data for each test scenario.

8.0 ACKNOWLEDGMENTS

Special appreciation is given to the active Fleet participants for their superb support during this demonstration. These participants included representatives from ATG *Mayport,* ATG *Norfolk,* USS *Thomas S. Gates* (CG 51) and PCU *Pinckney* (DDG 91). Special appreciation is also given to the crew of the ex-USS *Shadwell* and especially DCC (SW) Chelbi Cole for their dedication and hard work.

9.0 REFERENCES

1. Northrop Grumman Ship Systems, "DD(X) Damage Control Process and Organization," 28 February 2003

2. Carhart, H.W., Williams, F.W., and Toomey, T.A., "The Ex-*Shadwell* – Full Scale Fire Research and Test Ship," NRL Memorandum Report 6180.

3. Williams, F.W., Tatem, P.A., Nguyen, W., Durkin, A., Parker, A.J., Strehlen, B.D., Scheffey, J.L., Pham, H., Wong, J.T., Darwin, R.L., Runnerstrom, R., Lestina, T., Downs, R., Bradley, M., Toomey, T.A., and Farley, J.P., "Results of 1998 DC-ARM/ISFE Demonstration Tests," NRL/FR/6180-00-9929, April 25, 2000.

4. Peatross, M.J., Luers, A.C., Pham, H. V., Scheffey, J.L., Wong, J.T., Farley, J.P., Williams, F.W., Tatem, P.A., Nguyen, X., and Rose-Pehrsson, S.L., "Results of the FY 2000 DC-ARM Demonstration," NRL Letter Report 6180/0029, 7 February 2001.

5. Luers, A.C., Gottuk, D.T., Pham, H.V., Scheffey, J.L., Wong, J.T., Downs, R., Runnerstrom, E., Farley, J.P., Williams, F.W., Tatem, P.A., Durkin, A., Nguyen, X., and Buchanan, J., "FY 2001 DC-ARM Final Demonstration Report," NRL/MR/6180-02-8623, 31 May 2002.

6. USS *McFaul* (DDG 74) DC Locker Readiness Report, 12 February 1998.

7. Department of the Navy, "Naval Ship's Technical Manual (NSTM) Chapter 555 - Volume 1 Surface Ship Firefighting," S9086-S3-STM-010/CH-555V1, Naval Sea Systems Command, Revision 9, 1 December 2001.

8. Naval Sea Systems Command, "Operational Stations Book for DDG 51 Class Ships," Volume IV, Chapter 7, Damage Control, Technical Note No. 088-55W2-TN-0017, Naval Sea Systems Command, December 31, 1987.

9. Williams, F.W., Toomey, T.A., Scheffey, J.L., and Farley, J.P., "Preliminary Findings from Collective Protection System (CPS) Fire Fighting Workshop, 6-11 April 1992," NRL Ltr Rpt 6180-433: MW, August 31, 1992.

10. Carey, R.B., DiNenno, P.J., Forsell, E.W., and White, D.A., "Smoke Control Tests in a Simulated Machinery Space and Damage Control Passageway," CARDIVNSWC-TR-63-CR-93/05, August 1993.

11. Peatross, M.J., Scheffey, J.L., Hill, S.A., Nilsen, J.C., Williams, F.W., Farley, J.P., and Toomey, T.A., "Series 1 Results for Smoke Control Testing," NRL Ltr Rpt 6180/0185, April 23, 1998.

12. Peatross, M.J., Hill, S.A., Scheffey, J.L., Nilsen, J.C., Toomey, T.A., Farley, J.P., and Williams, F.W., "Series 2 Results for Smoke Control Testing," NRL Ltr Rpt 6180/0424, July 13, 1998.

13. Peatross, M.J., Scheffey, J.L., Hill, S.A., Nilsen, J.C., Williams, F.W., Farley, J.P., and Toomey, T.A., "Series 3 Results for Smoke Control Testing," NRL Ltr Rpt 6180/0538, November 19, 1998.

14. Back, G.G., Williams, F.W., DiNenno, P.J., Farley, J.P., Hill, S.A., Darwin, R.L., Toomey, T.A., and Havlovick, B.J., "Full-Scale Machinery Space Water Mist Tests: Final Design Validation," NRL Ltr Rpt 6180/0077, 24 February 24 1997.

15. Back, G.G., DiNenno, P.J., Leonard, J.T., and Darwin, R.L., "Full Scale Tests of Water Mist Fire Suppression Systems for Navy Shipboard Machinery Spaces: Part I – Unobstructed Spaces," NRL/MR/6180-96-7830, March 8, 1996.

16. Back, G.G., DiNenno, P.J., Leonard, J.T., and Darwin, R.L., "Full Scale Tests of Water Mist Fire Suppression Systems for Navy Shipboard Machinery Spaces: Part II – Obstructed Spaces," NRL/MR/6180-96-7831, March 8, 1996.

17. Kelly, A.A., Hill, S.A., Back, G.G., Scheffey, J.L, Tatem, P.A., Farley, J.P., Williams, F.W., "The Use of Sidewall Sprinklers and Water Mist Nozzles for Primary Damage Area (PDA(F)) Cooling," NRL Ltr Rpt in preparation.

18. Hill, S.A., Luers, A.C., Scheffey, J.L., Pham H.V., Farley, J.P., and Williams, F.W., "Test Plan for Evaluating Autonomic Fire Suppression System Concept of Operations and Primary Damage Area Cooling Effectiveness," NRL Ltr Rpt 6180/0205, May 2, 2003.

19. Bradley, M., Burns, S., Downs, R., Lestina, T., Roberts, M., Runnerstrom, E., Yufik, Y.M., Sheridan, T., Tatem, P.A. and Williams, F.W. "Damage Control Automation for Reduced Manning-Supervisory Control System Development-Phase I" NRL Memorandum Report NRL/MR/6180--00-8468 of June 26, 2000.

20. MPR Associates, Inc., "SCS Decision Logic Functional Analysis for September 2000 Demonstration Functions," MPR Serial No. 353 9801/51, May 26, 2000.

21. Naval Surface Warfare Center, "Damage Estimates for ex-*Shadwell* Modifications," NSWC Carderock Ser 3900 SCR 67-067 C 406, 21 August 1998.

22. Darwin, R.L., "U.S.S. *Stark* Battle Damage and Fire Protection Lessons Learned," 7th Quadripartie Conference of the International Exchange Project ABCA-7, Bath, U.K., March 1988.

23. Back, G.G., Darwin, R.L., and Williams, F.W., "Weapons Effect Test (Ex-USS *Dale* [CG-19]) Compartment Fire Evaluation," NRL Memo Report in preparation.

24. Back, G.G., Darwin, R.L., Scheffey, J.L., and Williams, F.W., "Propellant Fires in a Simulated Shipboard Compartment: Project HULVUL Phase III," NRL Memorandum Report Ser NRL/MR/6180–99-8394, 20 August 1999.

25. Back, G.G., Iqbal, N., Scheffey, J.L., and Williams, F.W., "Potential Compartment Fire Growth Curves Resulting From a Missile Hit," NRL Ltr Rpt Ser 6180/0526, 27 October 1998.

26. MPR Associates, Inc., "Operational Objectives for Firefighting," MPR Associates, Inc., prepared for Naval Sea Systems Command - NAVSEA 03R1, November 1997.

27. White, D.A., Rhodes, B.T., DiNenno, P.J., Tatem, P.A., and Kay, D., "Smoke and Fire Spread Evaluations: LPD-17 Amphibious Transport Dock Ship Total Ship Survivability and Battle Damage Repair Assessments," NRL Memorandum Report NRL/MR/6180–97-7985, 30 September 1997 (classified).

28. Darwin, R.L., Leonard, J.T., and Scheffey, J.L., "Fire Spread by Heat Transmission Through Steel Bulkheads and Decks," *Proceedings of IAS Conference on Fire Safety of Ships*, Institute of Marine Engineers, London, England, May 1994.

29. Williams, F.W., Scheffey, J.L., Hill, S.A., Toomey, T.A., Darwin, R.L., Leonard, J.T., and Smith, D.E., "Post-Flashover Fires in Shipboard Compartments Aboard ex-USS *Shadwell*: Phase V - Fire Dynamics," NRL/FR/6180-99-9902, May 31, 1999.

30. Naval Sea Systems Command, "Advance Change Notice (ACN) 3/A to NSTM 555 Volume 1, Revision 9 – Change to Machinery Space Doctrine for Water Mist and Heptafluoropropane Fire Extinguishing Systems," Draft 23 May 2003.